MASTERS THESIS IN PLANT BREEDING

PBR-80436, 36 ECTS

AGRO-ECOLOGICAL SUSTAINABILITY AND SEGREGATION OF GENETICALLY MODIFIED (GM) OILSEED RAPE (*BRASSICA NAPUS*) IN CANADA AND THE NETHERLANDS

DEPARTMENT OF PLANT BREEDING, WAGENINGEN UR

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EXECUTIVE SUMMARY

As the debate on genetically-modified (GM) crops continues in Europe, the European government is considering taking socio-economic and sustainability criteria into account for decision making on admissions of genetically modified organisms. This project compared oilseed rape production in the Canadian Prairies and the Netherlands, Canada being a major GM producer and the latter to a far lesser extent, in order to assess agro-ecological sustainability of GM and non-GM (conventional) production. Two aspects of agro-ecological sustainability were investigated: crop protection and productivity. In addition, these components were integrated using total factor productivity (TFP) to achieve a holistic picture of agro-ecological sustainability for each production system.

Contrary to previous studies, crop protection data from the Prairie Weed Management Survey suggested that herbicide use intensity (kg a.i./ha) has increased with the adoption of HT OSR in Canada, however this increase has not resulted in a greater environmental impact than that in conventional oilseed rape. Our results indicated an increase of 18.5% in herbicide use intensity and a slight decrease of 1.9% in environmental impact when all HT systems were combined. The most important difference between the present study and others was the time period over which conclusions were drawn, as crop protection practices improve over relatively long time spans. Similar to crop protection, simultaneous efforts in breeding and improvements in agronomic practice result in increased crop productivity. Based on annual rates of increase in yield from 1988 to 2010, our results did not support greater yields from HT varieties. In the literature however, some evidence exists for yield gains of up to 10% for HT cultivars over conventional. Possible explanations include ability for earlier sowing and reduced competition due to superior weed control. Oilseed rape yields in Europe remain approximately twice as large as those in Canada. Using TFP, an index of total system inputs over outputs, oilseed rape production in the Netherlands was deemed to be more sustainable than that in Canada. This was mainly due to higher yields in the Netherlands indicating higher use efficiency of inputs. Within Canada, GM and conventional oilseed rape had similar levels of agro-ecological sustainability and additional biocides in GM production did not affect overall sustainability. Tillage practices had a large effect on sustainability and as a result use of GM technology has potential to improve sustainability of oilseed rape production if zero-tillage practices are adopted concurrently. However, in 2002 only 35% of farmers growing glyphosate tolerant oilseed rape practiced zero-tillage.

Current systems of segregation of GM and non-GM for certified oilseed rape seed in western Canada have failed to meet quality guidelines of less than 0.25% off-types. Canadian experience in terms of coexistence of oilseed rape demonstrates the complexity and difficulty involved in coexistence management for this crop. With imports of GM products to the EU from North America likely to increase in future, there is a increasing pressure to develop and maintain large scale segregation systems in commodity transport, processing and handling systems.

1.0 Introduction

Genetically modified (GM) crops are prevalent around the world, causing one of the largest environmental debates in recent times. Globally, area of GM crops cultivated continues to break records. A 2009 report by the European Commission's Joint Research Centre (JRC) predicts the number of commercialized GM crops in the world to increase four-fold from about 30 different cultivars currently, to over 120 by 2015. In 2009, 77% of soybean, 49% of cotton, 26% of maize and 21% of oilseed rape hectares grown were GM (James 2009). As the number of countries permitting GM crops for cultivation grows, they continue to be banned for this usage in other nations, most notably within the European Union. Contrary to global trends, the number of EU member states allowing the cultivation of GM crops remains limited, and for the first time in 2009 adoption levels in terms of area decreased by 12,969 hectares or 12% from 2008 to 2009. Some of this decrease can be accounted for by discontinuation of cultivation of Bt maize in Germany at the end of 2008, as well as the economic recession and decreased total plantings of hybrid maize (James 2009). Nevertheless, EU policy-makers are struggling to implement coherent coexistence regulations in many member states. Besides limitations on cultivation, the EU has approved GM crops for import in several cases. The most important of these being transgenic glyphosate tolerant soybeans, which are imported in large quantities for use in food and feed. More recently GM oilseed rape (OSR) has been approved for import and processing, but not for cultivation. Increased imports of these GM products demand clear coexistence regulations in order to maintain segregation of the various supply chains and most importantly to maintain trust of EU consumers.

1.1 Beyond Safety: Sustainability of GM Oilseed Rape Production

Over the past 15 years, the issue of allowance of GMO's in the Netherlands, and above all in the EU, have been hotly debated in politics, with human health and environmental safety at the forefront of the discussion. To date there are no cases of GM food or feed causing clear adverse effects on human health or the environment. This is likely because of the extensive safety testing and regulations required by most states, including the EU. Recently, the Netherlands has taken the lead in moving the discussion beyond health and environmental safety, addressing socio-economic and sustainability issues surrounding the introduction of GM crops for cultivation as well. In Spring 2009, the decision was made by the Dutch government to take socio-economic considerations into account, particularly for cultivation of GMO's in the country, with the aim of providing a more holistic view of the impacts of such a decision. Similarly, the purpose of this report is to examine several aspects of agro-ecological sustainability of GM oilseed rape (OSR).

Sustainability has been a useful concept to promote change of common agricultural practice. In the GM debate, issues commonly raised include health risks, power relations, economics, legal rights, as well as those attributed to changes in management practices, such as agro-chemical usage (Figure 1.1). In terms of agriculture, sustainability can be defined as: "the *maintenance* of an agricultural system over time in good health and productivity and without degradation of the environment (Barnett et al. 1994)."

GM crops may contribute to increased agro-ecological sustainability in four potential ways, namely: i) reducing the impact from crop protection agents, ii) reducing the demand for

agricultural land, iii) stimulating agricultural practices that are beneficial to the environment, and iv) reducing environmental pollution during crop processing after harvest (Backus et al. 2008).

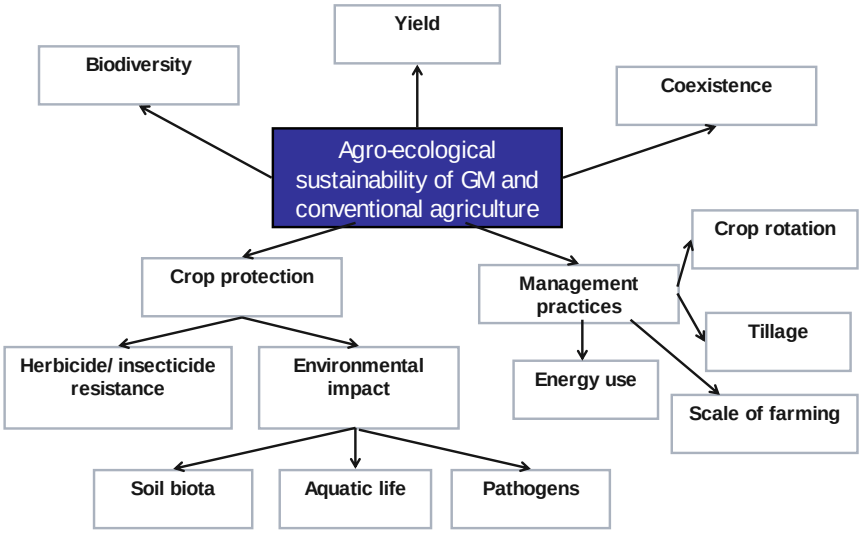


Figure 1.1. Agronomic and ecological impacts of cultivation of GM crops on agro-ecological sustainability.

1.2 Masters Thesis Objectives

As previously described, the political discussion has moved from questions of safety, to questions of sustainability of certain applications of GM crops, taking into account socio-economics and agro-ecological sustainability. This report focuses on agro-ecological sustainability, however a complete evaluation of all components involved in the environmental dimensions of sustainability of GM and conventional OSR was not feasible within this study (Figure 1.1). Therefore, this project focused on two components of agro-ecological sustainability of OSR production: 1) usage of crop protection agents, and 2) crop productivity. This delineation does not imply that other aspects are less relevant to sustainability or the GM debate. Rather, these could be considered in future research.

Next, crop protection and productivity aspects were integrated with economic and other environmental components to obtain a holistic view of sustainability of each system using: 3) total factor productivity (TFP). Finally: 4) practicality of coexistence in OSR will be investigated in Canada. While past studies have compared the effects of GM crops within Canada (Beckie et al. 2006, Brimner et al. 2005, Brookes and Barfoot 2005, Stringham et al. 2003, etc.), this report will provide new insights by comparing a mainly non-GM producing country, the Netherlands, and a major GM producer, Canada. By taking a broader perspective, this study aims to provide a more inclusive analysis of the potential agronomic and environmental impacts of cultivation of GM OSR.

1.2.1 General Objectives

- Collect and analyze data to determine effects of GM oilseed rape cultivars on usage of crop protection agents and crop productivity; as well as consider subsequent consequences for agro-ecological sustainability.
- Compare whole system sustainability of oilseed rape production to the farm gate in the Netherlands and Canada using the total factor productivity approach (TFP) (Glendining et al. 2009).
- Provide insight into coexistence for the case of oilseed rape in the Netherlands and Canada by discussing practical issues to be overcome.
- Communicate conclusions effectively to the project team within and outside of Wageningen UR.

1.2.2 Report Contents

This report is composed of 6 chapters.

1.0 Introduction
2.0 Crop protection in oilseed rape
3.0 Oilseed rape productivity
4.0 Comparing whole system sustainability using total factor productivity (TFP)
5.0 Coexistence in oilseed rape
6.0 Conclusions

1.3 Oilseed rape (OSR): An Introduction

Compared to other crops OSR is relatively weedy, with a lack of shattering resistance, persistent seed banks and average outcrossing rates of 30%. The potential agronomic, economic and environmental impacts of HT OSR cultivars make it an important crop for investigating sustainability of GM crops (Beckie et al. 2006). Historically, two species of OSR were grown in Canada, *Brassica rapa* or Polish canola and *Brassica napus* or Argentine canola, although production of *B. rapa* has decreased dramatically in the past decade. Due to inherently higher yields, all commercial HT OSR varieties are of the species *Brassica napus*. The term oilseed rape (or rapeseed) technically refers to both *B. napus* and *B. rapa*, but commonly only refers to *B. napus* types.

In the past, high levels of erucic acid caused rapeseed oil to taste bitter, and high glucosinolate caused digestive problems in livestock. In the 1970s, double-low cultivars of OSR were bred and given the name canola (CANadian Oil Low Acid) to distinguish them from varieties with high levels of erucic acid and glucosinolates. As a result, canola is the term commonly used in Canada and the United States, but essentially refers to any cultivar with the double-low trait. This report uses oilseed rape (OSR) to refer to *B. napus* mainly, and mentions when *B. rapa* cultivars are included.

1.3.1 Industry

With 5.9 Mha, GM OSR occupies 5% of the total world acreage of GM crops and 20% of the world acreage of OSR (James 2008). The greatest part of GM OSR is grown in Canada, where it encompasses 95% of OSR cultivation, with the rest of GM OSR mainly grown in the United

States. In Australia, the country is split. While South Australia has a ban on GM crops, West Australia has recently lifted its ban on cultivation of GM OSR and in 2008 cultivation resumed. Currently, import of OSR from North America into the EU-27 is limited (3 Kton in 2007). This is due to past bans on import of OSR seed from North America for fear of adventitious presence of an unapproved GM OSR variety, T45 (Bayer Crop Science). In March of 2009, T45 was approved for import into the EU, and imports from Canada and the US are likely to increase as a result. Commonly, OSR seed is crushed to obtain rapeseed oil, for either human consumption or industrial uses such as solvents, lubricants and biofuel production. With seeds containing approximately 40% oil, the remainder of the seed is processed into meal, for use as high protein feed for livestock.

1.3.2 Types

OSR was the first transgenic herbicide tolerant (HT) crop to become commercially available worldwide. Introduced to Canada in 1995, it has become by far the most extensively studied of Canada's transgenic crops (Beckie et al. 2006). The first HT cultivar available was resistant to triazine. However, the trait imposed a fitness penalty that caused lower productivity and cultivation of triazine resistant cultivars has been discontinued in Canada, but continue to be important in Australia where they are commercially viable. The bromoxynil tolerant system had a similar fate as triazine tolerant OSR in Canada. Bromoxynil controlled a limited number of broadleaf weeds and needed to be tank-mixed with clethodim for grass weed control (Beckie et al. 2006). As a result it could not compete with other systems on the market. GM cultivars currently available are tolerant to either: glyphosate (Roundup Ready) or glufosinate (Liberty Link), with cultivars resistant to glyphosate dominating the market (O'Donovan et al. 2006). Both of these types were developed using genetic engineering. A third herbicide tolerance trait, imidazolinone tolerance, was developed through conventional breeding (microspore mutagenesis), but after some initial market success, these varieties have decreased in popularity due to hybrid varieties with superior yields (Tan et al. 2005). Organic OSR cultivation is extremely minimal, as it is not economically viable due to low demand for such a product (Beckie et al. 2006).

1.3.3 Oilseed rape Cultivation in North-Western Europe

Although OSR is an important crop in arable farming systems in North-Western Europe, it is a relatively minor crop in the Netherlands (9.5 Kton in 2008; FAOstat). As a result, the majority of OSR products consumed in the Netherlands are imported from elsewhere, predominantly from within the EU. Major suppliers are Germany (26%), France (24%), Belgium (11%), Ukraine (11%), United Kingdom (8%) and Poland (7%). In general, OSR seed is transported to the Netherlands as seed and is crushed and processed within the country. In 2006, the Netherlands produced 60 Kton of oil and 79 Kton of meal mainly for domestic use. Historically, cultivation and production of OSR were greater and only recently, quantities have increased again due to increased demand for biofuels. In total the EU-27 grows 36% of the world's rapeseed oil production, 62% of which is destined for biofuels.

Although, environmental conditions across North-Western Europe differ only slightly, agricultural practices can vary considerably. The following describes the major OSR growing conditions, agronomic practices and prominent diseases in various parts of NW Europe:

Growing Conditions

- In general, NW Europe has a humid, temperate climate. To the west, the Netherlands has a mild, damp climate, while Denmark is more temperate. Germany and central and eastern France have a more continental climate characterized by warmer summers and colder winters than areas farther west. Precipitation is ample.
- Mainly podzolic soils characterized by moderate leaching, which in some places produces an accumulation of clay.
- Originally supported predominantly deciduous forest, but much has been removed to accommodate agriculture and dense population.

Agronomic practice

- OSR cropping is mainly confined to arable farms without a significant proportion of sugar beet, as OSR increases the occurrence of beet cyst nematodes in soils, which hinders subsequent beet yields. This is one major reason the area of OSR in the Netherlands is limited.
- Winter types of OSR are predominantly grown, with the exception of Denmark where spring types are traditionally more important.
- Rotations are ordinarily three-course rotations consisting of various cereals (for example winter wheat, winter barley, OSR). Highest input and shortest rotations are found in the UK, the Netherlands and the northern part of Germany.
- Plough-based tillage methods for winter OSR are generally practiced, however minimum tillage practices have been adopted in Eastern Germany where water conservation is important.
- Seeding occurs from the middle of August in the northern part of Germany and the UK, to the middle of September in the drier regions of southern Germany. Spring rape is normally sown during March and April, or as soon as soil conditions become favourable. Conventional seeding is generally used, but in Scandinavia, direct drill seeding has become popular.

Diseases

- Most damaging diseases are fungal, namely: light leaf spot (*Pyrenopeziza brassicae*), white rust/staghead (*Sclerotinia sclerotiorum*), blackleg (*Phoma lingam*) and *Alternaria*.
- Clubroot (*Plasmodiophora brassicae*) has become a problem in parts of northern Germany due to extended periods of growing OSR every second year or continuously for a number of years.

1.3.4 Oilseed rape Cultivation in Western Canada

In North America, oilseed rape is grown throughout the semiarid region of the Northern Great Plains, mainly in the southern part of the Canadian Prairies and North Dakota in the United States. Oilseed rape has a long tradition within cropping systems of Canada. According to a Statistics Canada survey, the area seeded with OSR in 2008 was the highest area ever at just under 6 million hectares, making Canada the second largest producer of rapeseed after China (12.1 million and 12.6 million tones produced in 2008, respectively; FAOstat). This report only looks at western Canada because it produces the vast majority of OSR in Canada (97% over the past 10 years; Canola Council of Canada; Figure 1.2).

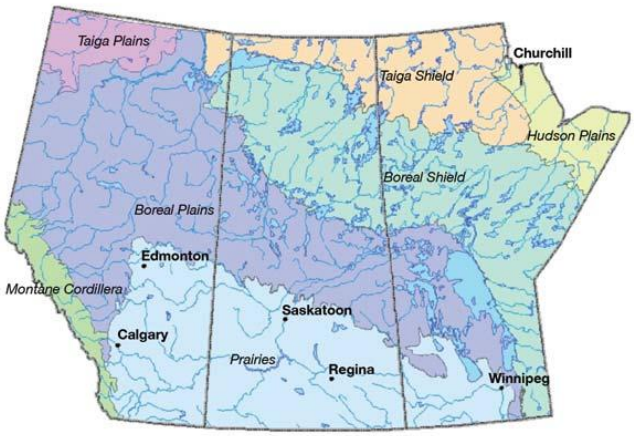


Figure 1.2. Ecozones of the Canadian Prairie provinces Alberta, Saskatchewan and Manitoba. This study focuses on the Prairie Ecozone only (shown in light blue).

Growing conditions

- Climate in the Prairies ranges from semiarid in the north to subhumid in the south, with long, cold winters, and short, very warm summers. Precipitation is generally low, but increases from west to east.
- Chernozemic soils support mainly grassland and range from black soil with high organic matter content in the subhumid region to less productive brown soils in the sub- to semiarid regions.

Agronomic practice

- Rotations similar to those in western Europe are common practice (typically, two crops of winter wheat, winter barley, then OSR as a break crop; Beckie et al. 2006). In this way, OSR offers a break in the cycle of weeds, pests and diseases associated with the prior crop and fits well in rotation as a summer crop preceding winter wheat.
- All OSR grown in western Canada is of the spring type since winter varieties cannot survive the harsh climate.
- Early spring seeding occurs as soon as conditions allow for seeding, ordinarily from late April to early May. In particularly cold winters, or in some areas, late spring seeding may be the only option occurring in late May. Thus, the growing season for cereals and oilseeds is generally recognized as four months in the Prairies (Government of Saskatchewan).
- Fields are seeded using direct drilling most often.
- Many farmers have adopted reduced or zero tillage cropping systems, in which non-selective herbicides are used instead of tillage to control weeds prior to crop seeding (Marvier and Van Acker 2005).

Diseases

- With the adoption of HT OSR, fields previously unusable for agriculture because of relatively high weed pressure are being used.
- Blackleg fungi (*Phoma lingam*) is the most important disease in Canadian OSR cultivation. Other major diseases (also fungal) are white rust/staghead (*Sclerotinia sclerotiorum*), and *Alternaria*.

The fundamental differences with respect to agricultural production of OSR in North-Western Europe and the Canadian Prairies are summarized in Table 1.1. Climate has the largest influence on differences between agriculture in the two locations. The moderated temperatures of western Europe allow for winter OSR to be grown, resulting in a much longer growing season compared to the Prairies. Farm size can have an important influence on fixed costs per farm as well as workload per hectare, which in turn influences timeliness of fertilizer and crop protection agent applications.

Table 1.1. Typical differences between OSR cultivation in North-Western Europe and Western Canada.

	NW Europe	**W Canada**
Climate	Maritime	Continental
Farm size	100 ha	600 ha
Growing season	Early September to mid-July	Early May to early September
Type of cultivars grown	Mainly winter	Only spring
Fertilizer input	180 kg N/ha	110 kg N/ha
Crop protection agent input	Pre-emergent, soil incorporated herbicides Relatively high amount of fungicide used	Mainly non-selective in-crop herbicides Relatively low amount of fungicide used

1.4 Why Grow Herbicide Tolerant Varieties?

Adoption of HT OSR was undeniably rapid. Following introduction in 1995, 87% of OSR hectares grown were transgenic by 2006 (Brookes and Barfoot 2009). Biotechnology companies often attribute this rapid adoption to superior pest control and even higher yields, however the reasons farmers elect to grow GM varieties are more difficult to uncover. In a survey of 298 OSR producers in Saskatchewan, Mauro and McLachlan (2008) found that although some growers thought that HT OSR resulted in higher yields, this was by far not the most important factor in their decision to grow GM types (Table 1.2). The key benefit and motivator to adopting transgenics was improved ease and efficiency of weed control. A majority (77%) of producers were pleased with the overall performance of their HT OSR and, when compared to a conventional equivalent, almost half (47%) believed it was more profitable (Mauro and McLachlan 2008). The most important reasons farmers gave in choosing not to grow GM varieties were cost-related, including market access and the Technology Use Agreement (TUA), which must be signed with Monsanto for use of glyphosate resistant varieties.

Table 1.2. Perceptions and experiences regarding the benefits and risks of herbicide-tolerant (HT) oilseed rape ranked by producers according to order of importance (n = 298). Benefits and risks were ranked from 1-10 with 1 being the item most commonly identified by farmers.

Rank	Item	Mean	SE
Benefits			
B1	Easier weed control	5.47	0.08
B2	Herbicide rotation	5.37	0.08
B3	Better weed control	5.28	0.08
B4	Reduced dockage	4.97	0.09
B5	Reduced need for tillage	4.66	0.09
B6	Higher yields	4.49	0.1
B7	Simpler pest management	4.39	0.09
B8	Less time required	4.36	0.1
B9	Environment	4.23	0.1
B10	Increased revenue	4.17	0.09
Risks			
R1	Loss of markets	5.87	0.08
R2	TUA* restricting rights	5.56	0.1
R3	Increased seed cost	5.36	0.08
R4	Lawsuits	5.2	0.1
R5	HT volunteers	5.08	0.09
R6	Gene spread	5.07	0.09
R7	Herbicide resistant weeds	5.02	0.09
R8	RR crops & tillage	4.98	0.1
R9	Seed saving	4.88	0.1
R10	Damage to non-target species	3.67	0.09

*Technology Use Agreement. Modified from Mauro and McLachlan 2008.

Improved weed control has resulted in a better quality product. Weed seed contamination of harvest survey samples decreased significantly as the herbicide tolerant lines increased in production (Daun 2004). Several studies have reported higher net returns for HT OSR production attributing benefits to greater yields, less dockage, improved seed quality, reduced herbicide costs, and reduced tillage costs (Canola Council 2001, O'Donovan et al. 2006, Brookes and Barfoot 2009).

1.5 Background

The following section provides some background for the issues investigated in this report: i) crop protection, ii) productivity, iii) total factor productivity (TFP), and iv) coexistence.

1.5.1 Crop Protection

The relative use of crop protection agents in GM and non-GM crops is often discussed in the GM debate. In this report the term biocide, or crop protection agent, refers to any chemical or mixture intended to prevent, destroy, or repel any pest, and includes herbicides, fungicides, insecticides and various other substances. Because OSR is grown in cooler climates, overall biocide use is generally less than in other crops, although even compared to crops grown at similar climates

quantities of biocide used are considerably lower; for example, 50% lower than sugar beet and 80% lower than maize. In addition, the majority of biocide use in OSR is herbicide, which is generally less toxic than other types of agro-chemicals.

Thomas and Leeson (2008) briefly compared biocide use intensity (kilograms of active ingredient/hectare) between parts of the EU and the Canadian Prairies for cereal and oilseed crops and made several initial observations (Figure 1.3).

- In general, levels of herbicide used in the Prairies were comparable or slightly greater than northern and eastern Europe.
- For oilseeds, herbicide use intensity in the Prairies was comparable to eastern Europe and slightly less than that for western Europe. For cereals, western Europe had much higher usage than the Prairies and the rest of Europe.
- Contrary to western Europe, eastern Europe and the Prairies had higher biocide use intensity for oilseeds than for cereals.
- In terms of type of biocides, the Canadian Prairies had higher herbicide use than Europe, but Europe had higher use of fungicides (data not shown).

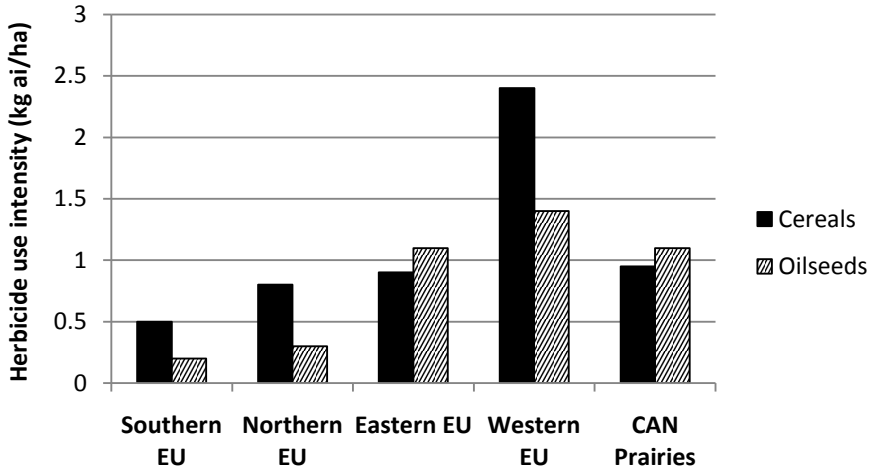


Figure 1.3. Southern Europe included: Portugal, Spain, Italy, Malta, and Greece; Northern EU: Denmark, Sweden, Finland, Estonia, Latvia, and Lithuania; Eastern EU: Czech Republic, Slovakia, Poland, Slovenia, and Hungary; western EU: Ireland, United Kingdom, Netherlands, Belgium, Germany, Luxembourg, France, and Austria. From Thomas and Leeson 2008.

Chapter 2 considers the current situation with regard to crop protection agent usage in GM and conventional OSR within western Canada and between conventional cultivation in the Prairies and western Europe. Herbicide usage will be assessed according to herbicide use intensity and environmental impact for the various OSR systems.

1.5.2 Oilseed rape Productivity

Evaluating yields is often challenging as so many factors may have a role that it is often difficult to know what increases or losses can be attributed to. In general, increases in yield reflect improvements in:

- Genetic yield potential of varieties (including disease resistance)
- Improved agronomic practices
- Better soil management, and fertilizer application practices.

Variability in these factors, in turn leads to high variability in yields, consequently it is difficult to distinguish the effect GM technology has had on yield in Canada. As indicated in Section 1.4.1, yield advantages were not a major reason producers choose to grow HT varieties in Canada. Mauro and McLachlin (2008) found that only 21% of growers believed HT OSR had higher yields. Current GM OSR varieties were not engineered to increase yields explicitly. However, increases in yield may result indirectly from less competition with weeds (herbicide tolerance). It is clear that HT OSR has allowed for better weed control, however whether or not this has resulted in clear increases in yield remains to be seen.

In general, yields of all crop species, including OSR, are much higher in western Europe than in the Canadian Prairies. With yields in the EU, already being much higher than in Canada, the proposed yield advantage of growing GM cultivars in Europe is potentially less. Therefore, it is of interest to determine if: i) GM varieties in Canada have resulted in increased productivity as well as ii) predict the potential effect they may have in Europe. This chapter also attempts to provide some explanation for the large differences in yield between the two locations.

Since OSR is not a major crop in the Netherlands, this study considers average yields over several western European countries, namely: Denmark, France, Germany and the Netherlands (Figure 1.4). Much larger variability in yields of the Netherlands may be due to its main use as a break crop as opposed to use solely for economic profitability. Recent environmental policies placing limitations on nitrogen fertilizer applications may also account for this variability (Peltonen-Sainio et al. 2009). Whatever the case, this is another reason that yield data from several countries were considered.

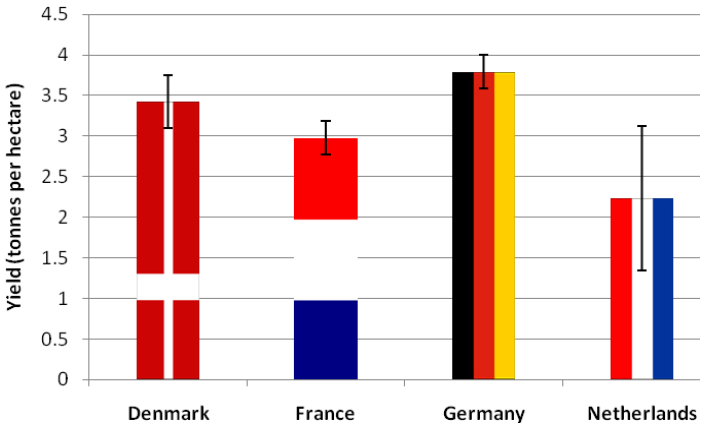


Figure 1.4. Five year average yield for all oilseed crops from 2004 -2009 in western European countries included in Chapter 3 of this study. Data from Eurostat.

1.5.3 Total Factor Productivity (TFP)

Chapter 4 of this report aims to incorporate the previous agri-environmental aspects into a broader view of sustainability of OSR production systems. This will be carried out using a measure of sustainability known as total-factor productivity (TFP), described in detail in Chapter 4. TFP values will be determined for the Netherlands and Canada, however due to the many differences between agriculture in the two countries, focus will be on differences between GM and conventional OSR cultivation in Canada, specifically biocide use and tillage practices.

1.5.4 Coexistence

Three different types of systems can be distinguished in agriculture: conventional, organic and genetically modified (GM) crop production. In the EU, the term coexistence is commonly used to refer to adequate separation of these production systems to ensure freedom of choice for growers and consumers. Coexistence and segregation imply the same concept, effectively referring to the simultaneous occurrence of all three production chains in parallel from agricultural fields to consumers without mixing, or co-mingling as it has been termed. In-field aspects of prevention of gene flow have been extensively studied in OSR, since it is the most problematic crop in this regard. Chapter 5 gives an overview of the results of these studies, and provides insight into managing coexistence by comparing situations in Canada and the EU.

1.6 References

Beckie HJ, Harker KN, Hall LM, Warwick SI, Legere A, Sikkema PH, Clayton GW, Thomas AG, Leeson JY , Seguin-Swartz G and Simard MJ. A decade of herbicide-resistant crops in Canada. Canadian Journal of Plant Science. 86(4):1243-1264.

Backus GBC, P Berkhout, DJF Eaton, L Franke, AJ de Kleijn, B Lotz, EM van Mil, P Roza and W Uffelmann. EU policy on GMOs; A quick scan of the economic consequences. 2008. LEI/Wageningen UR Report 2008-070. ISBN/EAN 978-90-8615-265-0.

Barnett V, S Landau and SJ Welham. 1994. Measuring sustainability. Environmental and Ecological Statistics. 1:21-36.

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

Canola Council of Canada. 2001. An agronomic and economic assessment of trangenic canola. Prepared by: Serecon Management Consulting Inc. and Koch Paul Associates.

Christen O, E Evans, C Nielsson and C Haldrup. 1999. Oilseed rape cropping systems in NW Europe. Proceedings of the 10th International Rapeseed Congress. Canberra, Australia.

Daun JK. 2004. Quality of genetically modified (GM) and conventional varieties of canola (spring oilseed rape) grown in western Canada, 1996-2001. Journal of Agricultural Science. 142:273–280.

Demont M and Y Devos. 2008. Regulating coexistence of GM and non-GM crops without jeopardizing economic incentives. Trends in Biotechnology. 26(7):353-358.

European Council (EC) Regulation 1829/2003 of the European Parliament and of the Council of 22 September 2003 on genetically modified food and eed. Official Journal of the European Communities L268, 1–23 http:// eur-lex.europa.eu/LexUriServ/site/en/oj/2003/l_268/l_26820031018en00010023.pdf.

European Union Joint Research Centre (JRC). 2009. The global pipeline of new GM crops: implications of asynchronous approval for international trade.

Government of Saskatchewan. 2008. Crops: Overview, Canola Production. Accessed December 1, 2009. http://www.agriculture.gov.sk.ca/Default.aspx?DN=a866a31e-266f-49aa-a3db-44f31dda65ea.

James C. 2009. Global status of commercialized biotech/GM crops: 2009. The first fourteen years, 1996 to 2009. 2009. ISAAA, Ithaca, NY.

Marvier M and RC van Acker. Can crop transgenes be kept on a leash? 2005. Frontiers in Ecology and the Environment. 3(2):99-106.

Mauro IJ and SM McLachlan. 2008. Farmer knowledge and risk analysis: postrelease evaluation of herbicide-tolerant canola in western Canada. Risk Analysis. 28(2):463-476.

O'Donovan JT, KN Harker, GW Clayton and RE Blackshaw. 2006. Comparison of a Glyphosate-Resistant Canola (*Brassica napus* L.) System with Traditional Herbicide Regimes. Weed Technology. 20:494-501.

Peltonen-Sainio P, Hakala K, Jauhiainen L and K Ruosteenoja. 2009. Comparing regional risks in producing turnip rape and oilseed rape: Impacts of climate change and breeding. Acta Agriculturae Scandinavica Section B. Soil and Plant Science. 59:129-138.

Thomas AG and JY Leeson. Quantity of plant protection products used on the Prairies: a comparison with the European Union. 2008. Agriculture and Agri-Food Canada, Research Centre, Saskatoon, Canada. Canadian Weed Science Society Meeting, November 25-27, 2008, Banff, Alberta.

Van Acker RC, Brule-Babel AL, Friesen LF. 2004. Intraspecifc gene movement can create environmental risk: The example of Roundup Ready® wheat in western Canada. In: Breckling, B and R. Verhoeven (eds): Risk, Hazard,

Damage – Specification of Criteria to Assess Environmental Impact of Genetically Modified Organisms. Bonn (Bundesamt fur Natursh utz) - Naturschutzund Biolische.

U.S. Canola Association. http://uscanola.com/index.asp?Type=B_BASIC&SEC=%7BA0D5E709-8C58-4023-BC36-857A410E99F3%7D

2.0 Crop Protection in Genetically Modified and Conventional Oilseed Rape in the Netherlands and Canada

2.1 Introduction

Prior to the introduction of herbicide tolerant (HT) OSR cultivars commercially in 1994, weed control was the major aspect influencing producers' decisions to grow OSR. The widespread adoption of HT varieties demonstrates the importance of the advantages provided by HT OSR to growers, with weed control being the most significant advantage. Glyphosate tolerant varieties particularly, in combination with reduced or zero tillage, are now even used in rotations as a clean-up crop for weeds in the Canadian Prairies. In the early 1990s, the most common treatments used in conventional (non-herbicide tolerant) OSR were pre-emergence, soil-incorporated herbicides, such as trifluralin and ethalfluralin (Table 2.1). Efficacy of these active ingredients was relatively low and longer soil residual activity resulted in some rotational restrictions on subsequent crops (Beckie et al. 2006).

Recently, the most commonly used HT cultivars in Canada, in descending order, are resistant to glyphosate (Roundup Ready), glufosinate (Liberty Link), and imidazolinone (Clearfield) (Canola Council of Canada). Both herbicide resistance to glyphosate and glufosinate were introduced to commercial OSR cultivars by genetic engineering techniques, while imidazolinone resistance was developed through conventional breeding (microspore mutagenesis; Tan et al. 2005). Adoption of these cultivars tolerant to herbicides with broad-spectrum foliar activity has led to a noted change in herbicide use from pre-emergence, soil-active herbicides to in-crop applications of herbicides such as glyphosate (Beckie et al. 2006).

Table 2.1. Common herbicide regimes for conventional and herbicide tolerant (HT) oilseed rape systems in the Canadian Prairies. LL = glufosinate tolerant, NT = non-herbicide tolerant (conventional), RR = glyphosate tolerant, CL = imidazolinone tolerant.

System	Treatment
1990s NT	trifluralin
	ethalfluralin
	other* (79 different treatments)
2000s NT	ethalfluralin
	glyphosate, ethametsulfuron, quizalofop
	other (25 different treatments)
2000s RR	glyphosate (2X in-crop)
	glyphosate (1X in-crop)
	other (11 different treatments)
2000s LL	glufosinate
	glyphosate, glufosinate
	other (22 different treatments)
2000s CL	imazamox, imazethapyr
	glyphosate, imazamox, imazethapyr
	other (28 different treatments)

* Other treatments referred to different combinations of active ingredients and number of applications. Various application rates are included.
From Leeson et al. 2006. Herbicide treatments were defined based on the main active ingredients (ai) applied and number of applications. For 1990s, number of fields (n)=235; for 2000s, NT n=42, RR n=161, LL n=63 and CL n=63.

This change in herbicide use has been documented in three main studies, Brimner et al. (2005), Brookes and Barfoot (2005) and Leeson et al. (2006). All authors used the EIQ method to assess environmental impact pre- and post-adoption of HT OSR.

2.1.1 An Introduction to the Environmental Impact Quotient (EIQ)

Originally developed by Kovach et al. (2000) for extension advice on integrated pest management in horticulture, the EIQ has been used by many authors for estimating and comparing the relative environmental impacts of crop protection programmes. EIQ values are unique for an active ingredient and act as a universal indicator of relative environmental impact of the given compound (Table 2.2). The equation to calculate an EIQ value consists of three main components accounting for potential adverse effects on: i) farm workers, ii) consumers and iii) ecology. Based on available toxicological data for the crop protection agent, each component is assigned an abstract numerical score and these components are averaged to obtain the EIQ value of an active ingredient. (Figure 2.1).

Table 2.2. Environmental impact quotient (EIQ) of common herbicide active ingredients in oilseed rape.

Active Ingredient	EIQ value (per kg a.i.)
2,4-D dichlorophenoxyacetic acid	24.00
clethodim	17.00
clopyralid	18.12
ethalfluralin	23.33
ethametsulfuron	19.86
fluazifop-P-butyl	28.71
glufosinate-ammonium	20.20
glyphosate	15.33
imazamox	19.52
imazethapyr	19.57
ipconazole	31.10
metolachlor	22.00
quizalofop	22.14
sethoxydim	20.88
trifluralin	18.80

From Cornell University, Integrated Pest Management Program: http://nysipm.cornell.edu/publications/eiq/. Accessed December 2009.

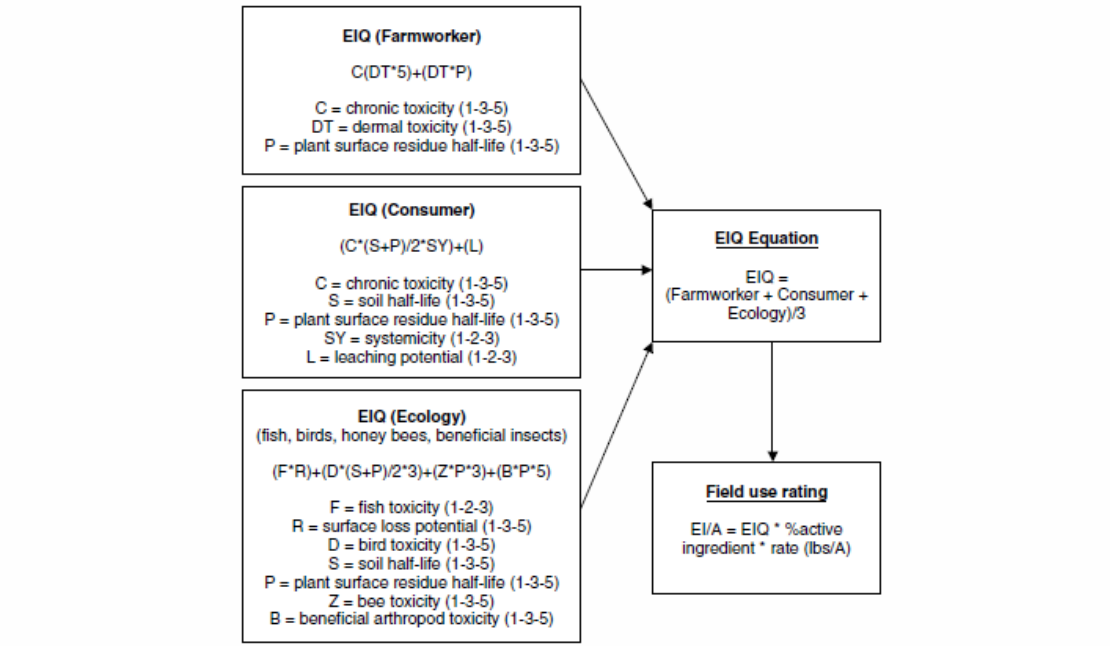


Figure 2.1. Components of the environmental impact quotient (EIQ). From Kleter 2008.

The EIQ value of a biocide can be used to estimate and compare the relative environmental impact of various crop protection products and systems rapidly and effectively. In a crop protection programme, the application rate of each active ingredient in the applied biocides is multiplied by the EIQ associated with that active ingredient to obtain the *field* EIQ. High EIQ values are associated with greater toxicity of an active ingredient, while high *field* EIQ values indicate greater environmental impact.

The scoring system basis for the EIQ has been criticized for the transformation of original values into classes and the high dependency of its estimates on quantity of biocide applied (Bues et al. 2003, Stenrod et al. 2008). The later property is partly due to a scoring system that does not include zero (1, 3 or 5), over allocating weight to heavily used biocides (Dushoff et al. 1994). In this way, EIQ approach over-simplifies the risks associated with biocide use. It is also important to note that EIQ values are not site specific and are dependent on factors that vary substantially with environment such as surface runoff and biocide transport in soil (Stenrod et al. 2008). Despite these drawbacks, for the comparative purposes of this study the EIQ approach is useful.

2.1.2 Objectives

The following objectives will be addressed in Chapter 2 of this report.

- To provide a comparison of herbicide use intensity (kilograms of active ingredient per hectare) in the various GM and non-GM OSR production systems within western Canada and between the Canadian Prairies and the Netherlands.
- To evaluate and compare the relative environmental impact of each OSR system, on a per hectare and per tonne of seed basis using the EIQ method.
- To summarize the effect of movement of the HT trait to non-tolerant OSR individuals and wild relatives of OSR on herbicide use.

2.2 Methods

Biocide use data for the Netherlands was obtained from the Praktijkonderzoek Plant & Omgeving B.V. (PPO) publication 301: *Akkerbouw en Vollegrondsgroenteteelt 2002 Kwantitatieve Informatie* (KWIN). Biocide use and other input values in this publication are updated on an annual basis and represent good agricultural practices typical for a given crop in the Netherlands. Data from Canada was provided by the Prairie Weed Management Survey carried out by Agriculture and Agri-Food Canada. This survey was conducted in 2001, 2002 and 2003 for the Prairie Provinces of Alberta, Manitoba and Saskatchewan, respectively. Currently, this is the most recent survey completed. Another survey was scheduled to be carried out in 2008, however was delayed due to a drought season. The Prairie Provinces represent approximately 99% of Canada's total OSR producing area (Canola Council of Canada).

This study included survey results from the Prairie Ecozone, which made up 73.6% of the OSR producing area in western Canada. The remainder was grown in the Boreal Plains Ecozone, but was omitted to limit geographic area somewhat. Within the Prairie Ecozone, data was collected by ecoregions characterized by brown, dark brown or black soils based on organic matter content. Ecoregions are shown in Figure 2.2, namely: the Aspen Parkland, Fescue Grassland, Lake Manitoba Plain, Mixed Grassland and Moist Mixed Grassland ecoregion (Figure 2.2). Herbicide use results include a range reflecting the number of responses to each survey question; in total 45-63 glufosinate tolerant, NT, 132-136 glyphosate tolerant, 40-56 imidazolinone tolerant, and 30-37 non-herbicide tolerant or conventional OSR fields were included (Table 2.3). In addition, data included survey results from 6 known *B. rapa* and 4 rapeseed fields. Conventional fields were located in low numbers across the whole area. Insecticide and fungicide use results were based on a similar number of fields (response numbers not shown).

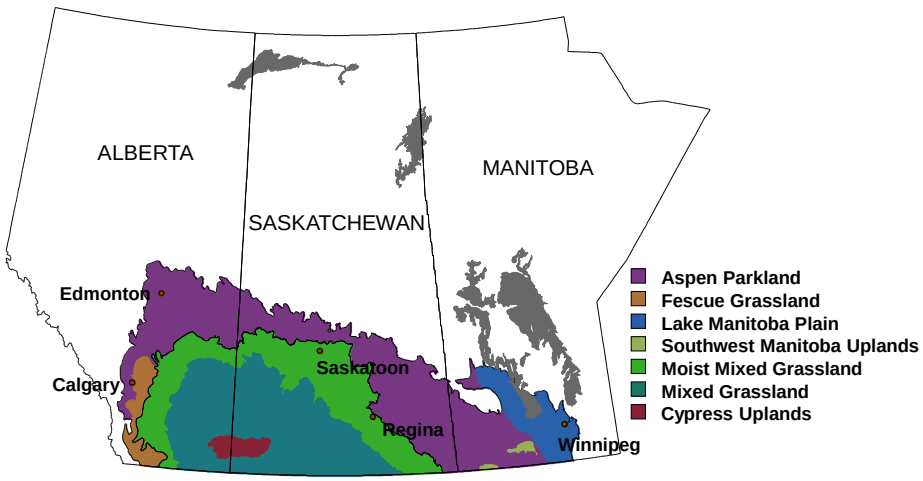


Figure 2.2. Ecoregions of the southern part of the Canadian Prairie provinces: Alberta, Saskatchewan, and Manitoba. Black lines show ecoregions combined by soil type (brown/dark brown & black) in data. This study included data from the Aspen Parkland, Fescue Grassland, Lake Manitoba Plain (black soils), Mixed Grassland and Moist Mixed Grassland (brown/dark brown soils). In addition, data from the smaller ecoregions, Cypress Uplands and Southwest Manitoba Uplands had few canola fields, and these fields were included with the brown/dark brown and black soil types, respectively.

Table 2.3. Number of fields included in determination of herbicide application rates for oilseed rape production systems in the Canadian Prairies. LL = glufosinate tolerant, NT = non-herbicide tolerant (conventional), RR = glyphosate tolerant, CL = imidazolinone tolerant.

Province	Main soil type	System	Number of Fields
Alberta	Black	LL	6-9
		NT	1-3
		RR	40-42
		CL	4-9
	Brown/dark brown	LL	1-3
		NT	5
		RR	5
		CL	1
Saskatchewan	Black	LL	10-13
		NT	2-3
		RR	32-33
		CL	11-12
	Brown/dark brown	LL	7-10
		NT	11-13
		RR	30-31
		CL	11-14
Manitoba	Black	LL	21-29
		NT	9-13
		RR	24-25
		CL	13-20

Number of fields in analysis included a range reflecting the number of responses to each survey question. Questions each corresponded to various application times. For example, a producer may have answered the pre-harvest, fall and spring sections but not the in-crop questions.
All data from the Prairie Weed Management Survey carried out in 2001-2003 by Agriculture and Agri-Food Canada. Ecoregions were combined into two groups based on main soil type: i) brown/dark brown soils - Mixed Grassland and Moist Mixed Grassland; ii) black soils - Aspen Parkland, Fescue Grassland, and Lake Manitoba Plain.

Biocide use intensity was calculated by multiplying application rate of an active ingredient by the area to which it was applied. Application area was recorded as a proportion of a given field treated. Pre-harvest the prior year, post-harvest the prior year, pre-emergence and post-emergence herbicide applications were summed and seed treatments were not included. Biocide use intensity (in kilograms active ingredient per hectare) associated with each system was calculated as the weighted average rate of the active ingredients applied for a given system in all three provinces. Fields surveyed were allocated to one of the major crop protection systems (ie. glyphosate tolerant, glufosinate tolerant, etc.) by Julia Leeson (Agriculture and Agri-Food Canada), based on crop variety and in-crop herbicide products. In terms of intensity of biocide use, herbicides are by far the most important type of product applied to OSR; for this reason this study concentrated on herbicides. In addition, most other studies have focused on herbicide use only, so this approach was also favoured for comparison purposes.

EIQ values for the various active ingredients are maintained by the New York State Integrated Pest Management (IPM) Program at Cornell University and are available online at: http://nysipm.cornell.edu/publications/eiq/default.asp. *field* EIQ was calculated for each active ingredient by multiplying the EIQ for a given active ingredient by its application rate (in kg a.i./ha) and these values were summed to give accumulated *field* EIQ for the various systems. In order to

look at herbicide use intensity and *field* EIQ as a comparison between HT and conventional (NT) OSR, the various HT systems were combined as a weighted average. Weights were based on land area of each HT system under cultivation and calculations appear in Appendix 2.1.

For metazachlor and metconazole EIQ values were not available and values for the closely related compounds metolachlor and ipconazole were used as substitutes. As previously stated in Section 2.2, EIQ of an active ingredient is determined using environmental and toxicological data known for the compound and these data are translated into a score for use in Equation 1. Toxicological and environmental behaviour data of the substitute compounds were checked with data for metazachlor and metconazole, respectively, in the Pesticide Properties Database (PPDB) maintained by the University of Hertfordshire. Relevant information for metazachlor and metconazole and their substitutes are shown in Appendix 2.2.

Finally, OSR yields in each country for 2002 were used to calculate EIQ per tonne of produce. This data was obtained from the KWIN 2002 (3.3 tonnes/ha) and the Prairie Weed Management Survey. Yields of the various systems in Canada were: glufosinate tolerant 1.8 tonnes/ha, non-tolerant (conventional) 1.3 tonnes/ha, glyphosate tolerant 1.4 tonnes/ha, and imidazolinone tolerant 1.4 tonnes/ha.

2.3 Results and Discussion

2.3.1 Herbicide Use Intensity

In OSR the vast majority of biocide applied is herbicide. The major herbicide in the Netherlands was metazachlor (Table 2.4a and b), while in conventional Canadian Prairie systems, the main herbicide used was ethalfluralin, followed by glyphosate and trifluralin (Table 2.5). Glyphosate was an important herbicide in all Canadian systems investigated including conventional (Table 2.5). Compared to glyphosate tolerance, all other systems used a wider variety of herbicide active ingredients, indicating that glyphosate tolerant growers used fewer non-glyphosate alternatives to control weeds, possibly a problem in prevention of herbicide resistant weed biotypes. Often crop protection systems require tank mixtures of herbicides, but this is generally not necessary in glyphosate tolerant systems. In glufosinate tolerant OSR, about one-third of producers tank-mix clethodim or other ACCase (acetyl coenzyme A carboxylase) inhibitors with glufosinate to enhance control of grasses (Leeson et al. 2006).

In both 2002 and 2009, about one third of the estimated environmental impact in the Netherlands was associated with the use of insecticides or fungicides, which is not as prominent in Prairie herbicide regimes (Table 2.4a and b; Table 2.5). This may be due to differences in ecological conditions between the two locations such as the drier, continental climate of the Prairies. It should be noted that since 2002 quantity and types of crop protection agents commonly used in the Netherlands has changed dramatically, with biocide use intensity in OSR dropping from 2.83 to 1.78 kg a.i./ha (Table 2.4b). For example, although metazachlor is still the main weed control agent in OSR, its use has decreased by one third in this time period.

Table 2.4a. Typical application rates of crop protection agents used in OSR cultivation in the Netherlands in 2002. EIQ, *field* EIQ and contribution of each active ingredient to the accumulated *field* EIQ is shown.

Active ingredient	Type	EIQ of active ingredient	Average quantity applied (kg active ingredient ha^{-1})	*field* EIQ per ha	Percentage of environmental impact
metazachlor	H	22.00	1.50	33.00	52.54
parathion-methyl	I	25.97	0.48	12.46	19.84
vinclozolin	H	17.39	0.50	8.70	13.84
nonylphenol-polyethoxy ethanol	H	22.70	0.25	5.68	9.04
fluazifop-P-butyl	H	28.71	0.09	2.69	4.29
deltamethrin	I	28.38	0.01	0.28	0.45
Accumulated *field* EIQ				**62.81**	100.00

Data from the KWIN 2002.

Table 2.4b. Typical application rates of crop protection agents used in OSR cultivation in the Netherlands in 2009.

Active ingredient	Type	EIQ of active ingredient	Average quantity applied (kg active ingredient ha^{-1})	*field* EIQ per ha	Percentage of environmental impact
metazachlor	H	22.00	1.00	22.00	52.80
iprodione	F	24.25	0.50	12.12	29.10
metconazole	F	31.10	0.09	2.80	6.72
fluazifop-P-butyl	H	28.71	0.09	2.69	6.46
clomazone	H	19.63	0.09	1.77	4.24
deltamethrin	I	28.38	0.01	0.28	0.68
Accumulated field EIQ				**41.67**	100.00

Data from the KWIN 2009.

Table 2.5. Typical application rates of crop protection agents used in OSR cultivation in several systems in western Canada in 2001, 2002, and 2003. EIQ, *field* EIQ and contribution of each active ingredient to the accumulated *field* EIQ is shown.

Active ingredient	Type	EIQ of active ingredient	Average quantity applied (kg active ingredient ha^{-1})	*field* EIQ per ha	Percentage of environmental impact
Non-herbicide tolerant (conventional) system					
ethalfluralin	H	23.33	0.31	7.25	45.34
glyphosate	H	15.33	0.20	3.00	18.80
trifluralin	H	18.80	0.14	2.71	16.96
sethoxydim	H	20.89	0.03	0.72	4.52
clopyralid	H	18.12	0.04	0.65	4.10
chlorpyrifos	I	26.85	0.02	0.42	2.63
other*					7.65
Accumulated *field* EIQ				**15.98**	100.00
Glufosinate tolerant system					
glufosinate ammonium	H	20.20	0.45	9.16	37.24
glyphosate	H	15.33	0.45	6.89	28.01
iprodione	F	24.25	0.17	4.09	16.63
ethalfluralin	H	23.33	0.07	1.63	6.61
benomyl	F	30.24	0.04	1.21	4.91
other					6.58
Accumulated *field* EIQ				**24.59**	100.00
Glyphosate tolerant system					
glyphosate	H	15.33	0.98	15.02	79.15
deltamethrin	I	28.38	0.04	1.06	5.60
chlorpyrifos	I	26.85	0.03	0.91	4.78
malathion	I	23.83	0.03	0.61	3.19
triallate	H	27.07	0.02	0.54	2.87
other					4.41
Accumulated *field* EIQ				**18.97**	100.00
Imidazolinone tolerant system					
glyphosate	H	15.33	0.38	5.87	55.84
trifluralin	H	18.8	0.06	1.16	11.01
ethalfluralin	H	23.33	0.04	0.86	8.18
clopyralid	H	18.12	0.04	0.69	6.56
sethoxydim	H	20.89	0.02	0.46	4.42
diquat	H	39.20	0.01	0.28	2.63
other					11.36
Accumulated *field* EIQ				**10.51**	100.00

*Crop protection agents accounting for less than 2.5% of environmental impact according to *field* EIQ.

On the Canadian Prairies, glyphosate and glufosinate tolerant systems had herbicide use intensities approximately 30% greater than conventional systems (Figure 2.3). These 2001-2003 levels of glyphosate and glufosinate tolerant OSR are comparable to those for conventional OSR from the Prairie Weed Management Survey in the mid-1990s (Leeson et al. 2006). This is important, since glyphosate and glufosinate tolerant systems were estimated to make up approximately 80% of all OSR area in 2006, and this number has likely risen since (Beckie et al. 2006). The much lower herbicide use in imidazolinone tolerant OSR (approximately 75% of conventional) is due to the low amount of in-crop active herbicide ingredients (Leeson et al. 2006). Unexpectedly, in-crop fungicide use associated with glufosinate tolerant OSR was greater than all other types (Figure 2.3). Although it is not reflected in our data, glufosinate tolerant varieties are the dominant type grown in Manitoba, which has a warm humid climate compared to the other provinces. This climate is very conducive to the development of *Sclerotinia* stem rot and as a result, all OSR production systems use more fungicides in this area. However, considering biocide use intensity for Manitoba only, higher usage of fungicides in glufosinate tolerant varieties was still evident. Reasons for this are unknown; but there are reports of increased disease occurrence in several glyphosate tolerant crop species including *Fusarium oxysporum* and *Fusarium avenaceum* in OSR (Johal and Huber 2009). It may be that a similar effect exists for glufosinate tolerant crops. Alternatively, other ecological factors may explain increased fungicide use intensity.

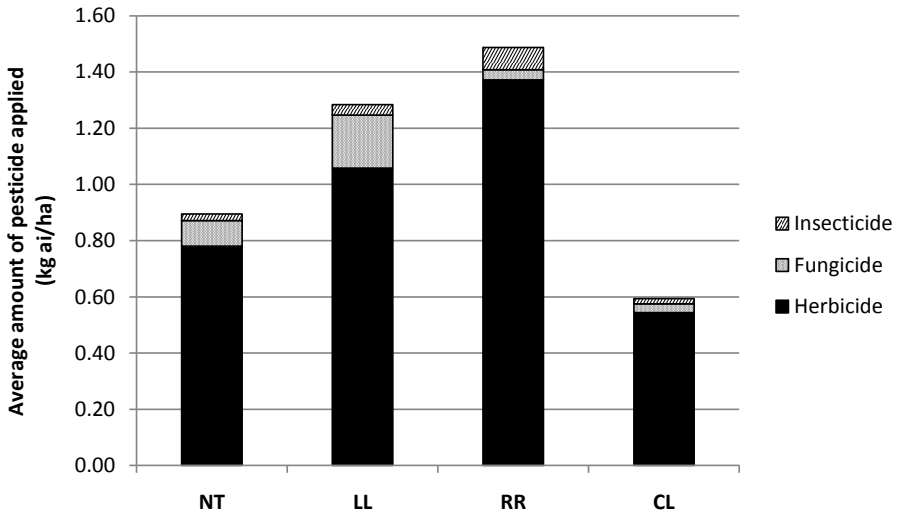


Figure 2.3. Biocide use intensity per system in western Canada (NT = non-herbicide tolerant, LL = glufosinate tolerant, RR = glyphosate tolerant, CL = imidazolinone tolerant). Seed treatments are not included.

For all HT types combined, herbicide use intensity (in kg of a.i.) was 18.5% greater than in conventional OSR production from 2001-2003 (see Appendix 2.1 for calculations). This value was weighted by area of OSR per system, and as a result would change if area planted to each HT system changed. In contrast, Brimner et al. (2005) found conventional rates consistently higher than those of HT OSR for individual years from 1996 to 2000. They found mean herbicide use in conventional OSR of 0.69 kg a.i./ha for this time period to be significantly greater than that of 0.34 kg a.i./ha for HT OSR (Brimner et al. 2005). However, this study did not use actual application rates and relied on several simplifying assumptions to calculate herbicide use intensity. Most importantly they assumed all herbicides were applied at the lowest recommended rate and that glyphosate, glufosinate and imidazolinone tolerant OSR was only sprayed with the respective

herbicide. Neither of these assumptions held true and herbicide use intensities were underestimated as a result (Leeson et al. 2006).

Brookes and Barfoot (2009) and Leeson et al. (2006) both estimated reductions of 12% in herbicide use intensity over all GM HT systems for the years following 1995 (Table 2.6). This may be the case, however they do not account for the simultaneous decrease herbicide use intensity in conventional OSR over this time period. As a result, these studies concluded that adoption of HT OSR resulted in reductions in herbicide use, when the majority of this reduction was due to lower herbicide use in conventional types. Using a larger subset of data from the Prairie Weed Management Survey (including the Boreal Plain Ecozone), Leeson et al. (2006) clearly showed greater herbicide use intensity for glufosinate and glyphosate tolerant systems than for conventional fields from 2001-2003. Looking at trends over time, they showed reduction in herbicide use intensity of 11.6% with the adoption of GM fields. However, they did not mention in their studies that without adoption, a decrease of approximately 25% occurred over this same time period in conventional canola alone. Changes in herbicide use in conventional OSR were not as important in the present study because we focused on data from three consecutive years only.

There are several valid reasons for conducting these comparisons over longer time frames, the most important being to limit the effect of variability in conditions between years. Furthermore, there is now relatively little area of conventional OSR cultivated on the Canadian Prairies. Therefore, it is possible that non-adopters of HT technology tend to be different than HT adopters with respect to other agronomic practices. If this is the case, then a comparison to the past may be more valid. At the same time, within year comparisons are still representative for a given season, with for example comparable weather conditions. More recent survey data from western Canada will be important to determine if findings of this study are consistent over a longer time frame.

Table 2.6. Past studies of herbicide use in oilseed rape in western Canada since introduction of herbicide tolerant varieties.

Publication	Decrease in herbicide use intensity (kg ai/ha)*	Decrease in environmental impact (*field* EIQ per hectare)	Time period	Data sources
Brookes and Barfoot 2009	12%	20%	1996-2007	Canola Council 2001, Canola Council Weed control guide
Leeson et al. 2006	11.6%	22.0%	1995-2003	Prairie Weed Management Survey (1990s and early 2000s)
Brimner et al. 2005	42.8%	36.8%	1995-2000	Lowest recommended application rate from crop protection publications for the province of Saskatchewan
Brookes and Barfoot 2005	9.7%	20.7%	1996-2004	Canola Council 2001

* For all OSR grown, conventional and herbicide tolerant.

2.3.1.1 Influence of Zero Tillage

Many factors determine mean rates of herbicide application including target yield, crop area and other factors. However, changes in these factors are more likely to play a role in data over many

years (Kleter 2008). Major changes in crop production in the Prairie Provinces besides the adoption of HT cultivars occurred in the decade following 1995. In particular, the adoption of zero and reduced tillage as well as the increased use of glyphosate in fall and pre-seeding would influence herbicide use in conventional OSR production. In the 1990's ethalfluralin and trifluralin were the most commonly applied herbicides for OSR in the fall or spring. These herbicides do not fit well in the reduced tillage systems as they require soil incorporation. Therefore, a trend towards a greater reliance on glyphosate was not solely due to HT OSR, but also to reduced tillage practices (Marvier and van Acker 2005). This is evident as levels of glyphosate applied in conventional systems also rose from 0.17 to 0.25 kg a.i./ha after the mid1990s (Leeson et al. 2006). The subsequent reduction in herbicide use intensity in conventional OSR may have shown the future of conventional OSR in reduced tillage systems without the introduction of HT varieties. Benefits to the environment such as improved soil biology, soil moisture, and less erosion have been well documented for reduced tillage practices (Lafond and Clayton 2009). This balance between potential increased herbicide use and reduced environmental impacts will be explored in Chapter 4.

Comparing western Canada and the Netherlands, the average amount of herbicide applied in the Netherlands was much greater (Figure 2.4). For North-Western Europe there is virtually no information available for HT OSR since it is not grown commercially. For cultivation of GM crops in Europe, the Farm Scale Evaluations (FSE) in the UK compared GM HT OSR and conventional OSR in field trials carried out across the country (Firbank et al. 2003). They concluded that the amount of active herbicide ingredient applied per hectare did not differ between HT and conventional OSR. However, it has been noted that a significant difference may not have been detected due to the relatively low amounts of herbicide used in OSR overall compared to other crops. Since the main objective of the FSE was the assessment of effects on biodiversity, no EIQ calculations were performed.

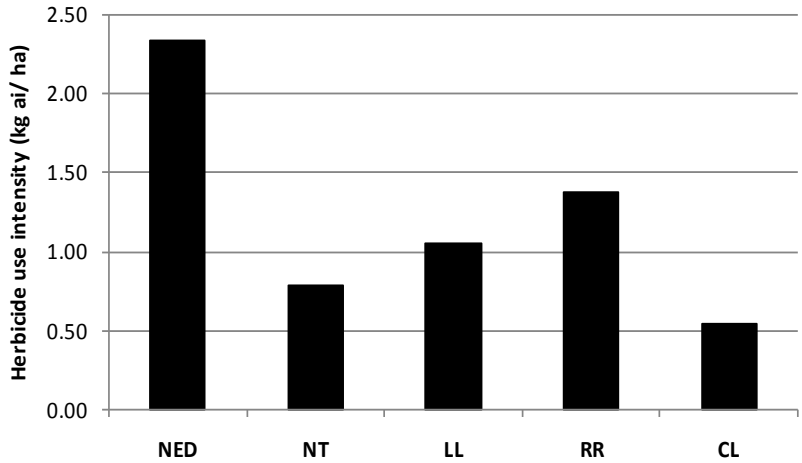


Figure 2.4. Herbicide use intensity in the Netherlands (conventional), and several systems in western Canada (LL = glufosinate tolerant, NT = non-herbicide tolerant, RR = glyphosate tolerant, CL = imidazolinone tolerant).

2.3.2 Environmental Impact Analysis

Given the basis of the EIQ on current toxicological and environmental characteristics of the biocide, values for various active ingredients are constantly being updated by Cornell University. In 2008, the EIQ value for the active ingredient, glyphosate was increased from 15.53 to 25.33, an increase of 39% (Table 2.7). Due to the widespread use of glyphosate, there was concern that new estimates of environmental impact would be dramatically increased from previous values. Fortunately, after further investigation it was determined that a software error in source data used by Cornell caused this change (K. Lewis, *personal communication*).

Table 2.7. Recent changes in glyphosate EIQ value over time. Relevant publications using the various EIQ values are shown.

Year	EIQ value	Publications
2004	15.30	Brookes and Barfoot 2005
2005	32.4	Brimner et al. 2005
2006	15.53	Leeson et al. 2006
2008	25.33	Temporary error
late 2009	15.33	Brookes and Barfoot 2009

Environmental impact estimated using the EIQ method resulted in the same relative order as herbicide use per hectare for Canadian systems, with the exception of glufosinate tolerance. Due to the relatively low EIQ value of glyphosate compared to glufosinate (15.33 and 20.20), glufosinate tolerant systems had the greatest environmental impact per hectare (Table 2.5). These results showed slight deviation from the results of Leeson et al. (2006) who found the relative impact of glyphosate tolerant OSR to be slightly less than conventional. In any case, only glufosinate tolerant OSR had an environmental impact notably greater than conventional OSR production. Overall, adoption of HT OSR resulted in a decrease in environmental impact of 1.9% compared to conventional OSR (for herbicides only; Appendix 2.1).

Consistent with herbicide use intensity, Brookes and Barfoot (2009) and Leeson et al. (2006) estimated that the use of HT canola reduced environmental impact by 20 and 22%, respectively (Table 2.6). This raises the same issue discussed in Section 2.2.1 with respect to crop protection practices over time. Brookes and Barfoot's (2009) conclusions were based on values which do not correspond to those collected in the Prairie Weed Management Survey. They used a herbicide use intensity of 1.13 kg a.i./ha for conventional fields, much greater than the amount determined from the current survey (0.76 kg a.i./ha; Table 2.8). Brookes and Barfoot (2009) reference a combination of the Canola Council weed control guide and a 2001 Canola Council of Canada report, however this guide does not mention any specific application rates and the Canola Council report used incomplete data. In the Canola Council report, herbicide use data obtained from a survey (July 2000 Canadian Farmers' Herbicide Use Study) was summarized into a single representative treatment for glyphosate, glufosinate tolerant and conventional fields, and as a result the situation was oversimplified. Imidazolinone tolerant fields were also excluded. Brimner et al. (2005) calculated a greater overall reduction in environmental impact of 37%, despite use of a much higher EIQ value for glyphosate (Table 2.7). The difference between their result and ours

emphasizes the problem in using the assumption that herbicides were applied at the lowest recommended rates to determine EIQ (Table 2.8; see Section 2.3.1).

Table 2.8. Studies of herbicide use in oilseed rape in western Canada since introduction of herbicide tolerant varieties.

	Average quantity applied (kg a.i. ha^{-1})*			Data Source
	Conventional (non-tolerant)	**Glyphosate tolerant**	**Glufosinate tolerant**	
Present study	0.78	1.37	1.06	Prairie Weed Management Survey (2001-2003)
Brookes and Barfoot 2009	1.13	1.12	0.44	Canola Council 2001, Canola Council Weed control guide
Brimner et al. 2005	0.69	0.34 (combined)		Lowest recommended application rate from crop protection publications for the province of Saskatchewan

*Note that these values are for herbicides only and as a result differ from those in Table 2.5.

For the Netherlands, the relatively high intensity of biocide use resulted in a greater environmental impact per hectare than Canadian systems (Tables 2.4a & 2.5). Lutman et al. (2007) commented that the use of trifluralin in conventional systems contributes to a lower environmental impact in Canada compared to the use of metazachlor in Europe (EIQ of 22.00 for metazachlor and 18.80 for trifluralin). However, the environmental impact was mainly attributable to greater herbicide use intensities in this case.

2.3.2.1 Food Production and Crop Protection

Reductions in biocide use can be achieved by various means and should be considered within context (Gallivan et al. 2001). For example, biocide use in agriculture could be reduced by 50% by eliminating 50% of the area farmed and importing the food produced from other jurisdictions, thereby merely transferring the biocide use. Ideally, biocide use is reduced by reducing the number of applications and/or the amount applied in each application. However, without the introduction of other methods of pest control this practice could result in decreased productivity. To consider this aspect, *field* EIQ per tonne of produce was determined using typical yields of 3.3 tonnes/ha for the Netherlands and 1.3 tonnes/ha for Canada.

Despite the relatively high environmental impact of crop protection per hectare, in terms of productivity, OSR in the Netherlands has an environmental impact similar to that in Canada (15.17 for the Netherlands and 11.98 for glyphosate tolerance in Canada; Figure 2.5). This also reflects the difference between the intensive and extensive nature of agriculture in the respective locations. This aspect will be discussed in more detail in Chapter 4.

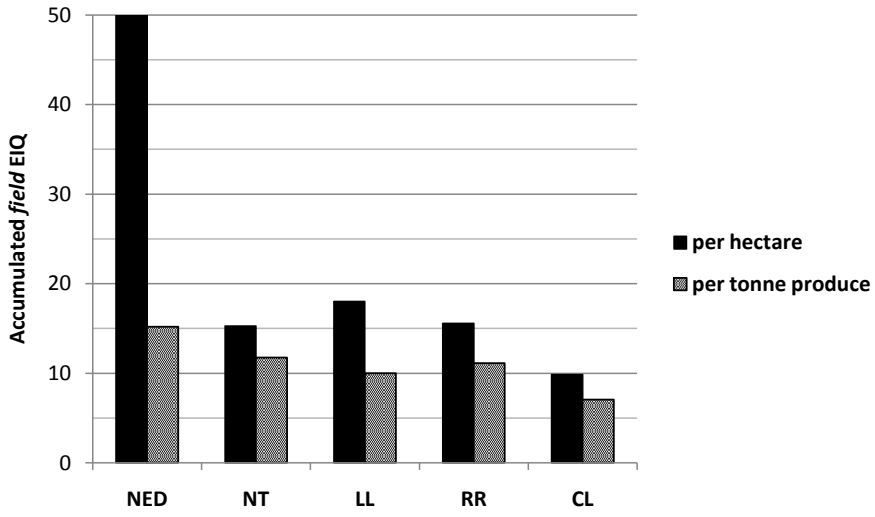


Figure 2.5. Accumulated *field* EIQ for crop protection agents used per hectare and per tonne of produce in OSR cultivation in the Netherlands (NED) and several systems in western Canada (LL = glufosinate tolerant, NT = conventional, RR = glyphosate tolerant, CL = imidazolinone tolerant). Herbicides, insecticides and fungicides were included.

2.3.3 Effect of Gene Flow on Herbicide Usage

Movement or "escape" of HT genes has been widely reported in OSR, especially in western Canada (Friesen et al. 2003). Its occurance across large areas, partial outcrossing reproductive system and weedy attributes such as volunteerism and seed shattering, make gene flow in OSR a larger potential problem than in other crop species (Knispel et al. 2008). Harvesting operations may result in the creation of seedbanks of 3 000 seeds/m^2 which can persist for years (Lutman et al. 2007). As a result, gene flow via seed has the potential to influence agriculture temporally and on a much larger spatial scale than via pollen (Beckie et al. 2006). On the other hand, outcrossing via pollen has been reported extensively in transfer of the HT trait to non-tolerant individuals and occassionally to wild relatives (Warwick et al. 2004). Via seed or pollen, development of HT voluteers and weeds are of concern for the long term effectiveness of herbicides used on HT crops.

2.3.3.1 Herbicide Tolerant Crop Volunteers

Volunteer OSR (whether HT or not) is a problem in both conventional and HT OSR cultivation, however HT voluteers may pose new challenges. In HT OSR fields, occurrence of HT volunteers in subsequent rotation crops is widespread due to seed loss in-crop and during harvesting. Differences in persistence of seeds has been observed, however this varies with genetic differences between cultivars, environment and agronomic practices, but is not associated with the presence of the HT trait (Gulden et al. 2003).

Whether the HT individual arises from seed or outcrossing by pollen, management is the same. Most commonly producers will control volunteers using herbicides, but with HT volunteers the main post-harvest and pre-seeding (in zero-tillage) herbicide (glyphosate) becomes unavailable. In this case, the herbicide can be replaced by alternative herbicides such as glufosinate, MCPA or 2,4-D. In Canada farmers have had to alter their practice to now commonly include an additional herbicide such as 2,4-D in their pre-seeding glyphosate application (Beckie et al. 2006). The now ubiquitous appearance of glyphosate tolerant volunteer OSR in western Canada necessitates the

use of this type of herbicide, even for those not growing HT varieties (Marvier and Van Acker 2005). In imidazolinone tolerant OSR, the problem is further complicated. Since imidazolinone tolerant OSR is not sensitive to ALS group herbicides, volunteers possessing imidazolinone tolerance may remain in fields of cereals, sugar beet, field pea and potatoes, where often only ALS inhibitors are applied (Lutman et al. 2007).

In a Canadian survey, 38% of HT farmers had experienced HT volunteer canola on their land and growers identified HT volunteers as the largest operational risk associated with HT OSR, after economic and political risks (Mauro and McLachlan 2008). Farmers relied on a variety of control methods, including, in ascending order of importance, hand pulling (1%), glyphosate (5%), others such as chemicals or letting the volunteers grow (7%), sweeps on the air seeder (9%), glyphosate and additional herbicide (17.5%), tilling (17.5%), and a combination of these techniques (43%). Many (9%) of the zero-till farmers in this study actually reverted to tillage to control RR volunteers (Mauro and McLachlan 2008). The combination of tillage and a variety of additional herbicides used may be the reason increased herbicide use intensity and the resulting environmental impact is not clearly associated with growing HT OSR.

Cultivation of the various HT systems simultaneously has resulted in appearance of volunteer and feral OSR plants with multiple HT traits in western Canada (Hall et al. 2000, Knispel et al. 2008). Management of HT OSR volunteers is effectively the same as that of single trait volunteers. Of course, herbicides available for weed control in subsequent crops become more limited, but in practice there are currently adequate herbicides available for this purpose (Beckie et al. 2006). In an extensive study of potential environmental impact of herbicide treatment of OSR volunteers in follow-up rotation crops in the UK, Lutman et al. (2007) concluded that there would be little or no added impact on the environment, despite the added use of 2,4-D. Although in agreement with Mauro and McLachlan (2008), they mention that farmers have to carry the added herbicide costs.

2.3.3.2 Hybrids with Wild Relatives

One concern often expressed with the cultivation of HT OSR is the movement of HT traits to wild relatives, potentially producing new weed biotypes. Although it is well documented that hybridization of HT OSR with wild relatives occurs (mainly with *Brassica rapa*), these claims have been largely unrealized (Warwick et al. 2004). Abundance of hybrid HT individuals will depend on flowering time of wild OSR relatives and OSR crops, compatibility (or ploidy level) and their occurrence in the same region. In Canada, occurrence of these individuals remains rare and associated environmental impact are essentially negligible.

2.3.4 Herbicide Resistance

For farmers, management of herbicide resistant weeds is essentially the same as HT volunteers, and usually involves: applying additional herbicide active ingredients, increasing application rates, or increasing number of applications (Lutman et al. 2007). Although there are no reports of glyphosate resistant weeds in western Canada to date, many glyphosate tolerant weed biotypes have developed in the United States and Austraila. Many of these resistances are thought to be a consequence of high glyphosate selection pressure in continuous rotations of GM glyphosate tolerant crops, mainly soybeans, maize and cotton (Beckie et al. 2006). In Canada, it is difficult to

know if glyphosate tolerant OSR plays a large role in glyphosate selection pressure in weed populations, partially because glyphosate use on HT OSR is much lower compared to other HT crops (Beckie et al. 2006; van Acker et al. 2003). However, it is clear that the change in the use of glyphosate from out of crop to in-crop use has greatly increased selction pressure for glyphosate resistant weeds and that continued use of glyphosate has resulted in 'weed shifts' towards species that are intrinsically more glyphosate resistant (Beckie et al. 2006). Similar effects have not been recorded, to date, with glufosinate, but it is much less widely used than glyphosate. Another important factor may be that HT OSR is usually grown in rotations with non-HT cereals. Development of herbicide resistant weeds generally poses a greater risk in unrelated weed species than hybridization of HT crops with related species due to the presence of selection pressure (Warwick et al. 2004).

2.4 Conclusions

Past studies have found that following the introduction of HT OSR to Canada in the mid-1990s, herbicide use intensity as well as environmental impact per hectare has decreased (Brookes and Barfoot 2009, Leeson et al. 2006, Brimner et al. 2005). However, these studies considered changes in herbicide use over relatively long time periods and in doing so included reductions in herbicide use, which were due to factors other than HT technology. Additionally, Brookes and Barfoot (2009) and Brimner et al. (2005) used lower quality data than the present study, resulting in overestimation of the benefits of HT OSR. Increased use of glyphosate in fall and pre-seeding as well as adoption of zero and reduced tillage practices have been major changes in crop production in the Canadian Prairie provinces that likely influenced herbicide use in the decade following 1995.

Contrary to others, the present study found that:

- Herbicide use intensity in the Canadian Prairies was 18.5% greater in HT than conventional OSR from 2001-2003 (including imidazolinone tolerant varieties).
- Despite this increase in herbicide use intensity, environmental impact of conventional and HT OSR production was similar overall.
- More specifically, adoption of HT varieties reduced environmental impact by 1.9% compared to conventional, but this was much less than estimates of 20%-37% of prior studies (Brookes and Barfoot 2009, Leeson et al. 2006, Brimner et al. 2005).
- More recent surveys in western Canada will be important to determine conclusiveness of these findings.
- Intensive OSR production in the Netherlands had a larger environmental impact per hectare than that in Canada. However in terms of productivity (environmental impact per tonne of produce), environmental impact was similar to Canadian production (both GM and conventional).

Although it has been considered valid to conduct herbicide use studies over many years, in this case the large effect of changes in agronomic practice over time confounded influence of the HT trait. In future, the best option may be to consider trends over many years, but to consider values on a year by year basis.

2.5 References

Beckie HJ, KN Harker, LM Hall, SI Warwick, A Legere, PH Sikkema, GW Clayton, AG Thomas, JY Leeson, G Seguin-Swartz and MJ Simard. 2006. A decade of herbicide-resistant crops in Canada. Canadian Journal of Plant Science. 86:1243-1264.

Brookes G and P Barfoot. 2005. GM crops: the global economic and environmental impact -the first nine years 1996–2004. AgBioForum. 8(2&3):187-196.

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

Bues R, M Dadomo, JP Lyannaz, G Di Lucca, JI Macua Gonzalez, H Prieto Losada and Y Dumas. 2003. Evaluation of the environmental impact of the pesticides applied in processing tomato cropping. Proc. 8th IS on Processing Tomato. Eds.: B. Bieche and X. Branthome. Acta Horticulture. 613, International Society for Horticultural Science.

Canola Council of Canada. 2001. An agronomic and economic assessment of trangenic canola. Prepared by: Serecon Management Consulting Inc. and Koch Paul Associates.

Dushoff J, B Caldwell and CL Mohler. 1994. Evaluating the environmental effects of pesticides: a critique of the environmental impact quotient. American Entomologist. 40:180-184.

Footprint, pesticide properties database (PPDB). Agriculture & Environment Research Unit (AERU), University of Hertfordshire. http://sitem.herts.ac.uk/aeru/footprint/en/ Accessed on November 16, 2009.

Friesen LF, AG Nelson and RC Van Acker. 2003. Evidence of contamination of pedigreed canola (*Brassica napus*) seedlots in western Canada with genetically engineered herbicide resistance traits. Agronomy Journal. 95:1342-1347.

Gallivan GJ, GA Surgeoner and J Kovach. 2001. Pesticide risk reduction on crops in the province of Ontario. Journal of Environmental Quality 30:798–813.

Graef F. 2009. Agro-environmental effects due to altered cultivation practices with genetically modified herbicide-tolerant oilseed rape and implications for monitoring: A review. Agronomy for Sustainable Development. 29:31-42.

Gulden RH, SJ Shirtliffe and AG Thomas. 2003. Harvest losses of canola (*Brassica napus*) cause large seedbank inputs. Weed Science. 51:83-86.

Johal GS and DM Huber. 2009. Glyphosate effects on diseases of plants. European Journal of Agronomy. 31:144-152.

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

Knispel AL, SM McLachlan, RC van Acker and LF Friesen. 2008. Gene flow and multiple herbicide resistance in escaped canola populations. Weed Science. 56:72-80.

KWIN. 2002. Praktijkonderzoek Plant & Omgeving B.V. (PPO) publication 301: Akkerbouw en Vollegrondsgroenteteelt 2002 Kwantitatieve Informatie (KWIN).

KWIN. 2009. Praktijkonderzoek Plant & Omgeving B.V. (PPO) publication 383: Akkerbouw en Vollegrondsgroenteteelt 2009 Kwantitatieve Informatie (KWIN).

Lafond GP and GC Clayton. 2009. Dispelling myths and making progress with no-till on the Canadian Prairies. Agriculture and Agri-Food Canada. Proceedings of the Landscapes Transformed: The Quiet Triumph of Conseravation Tillage and Direct Seeding. University of Saskatchewan. Saskatoon, Canada. March 25, 2009.

Leeson JY, AG Thomas, HJ Beckie, CA Brenzil, LM Hall, T Andrews, KR Brown and RC van Acker. 2006. Herbicide-use trends in prairie canola production systems. Proc. 2006 Soils and Crops Workshop, University of Saskatchewan, Saskatoon, Saskatchewan, Canada. pp. 7.

Lutman PJW, K Berry, MJ May, GT Champion, JH Clarke and SK Cook. 2007. Rothamsted Research, Rothamsted Research – Broom's Barn, and ADAS Boxworth. Agronomic and environmental implications of the establishment of GM herbicide tolerant problem weeds (project CPEC 45).

Marvier M and RC van Acker. Can crop transgenes be kept on a leash? 2005. Frontiers in Ecology and the Environment. 3(2): 99-106.

Mauro IJ and SM McLachlan. 2008. Farmer knowledge and risk analysis: postrelease evaluation of herbicide-tolerant canola in western Canada. Risk Analysis. 28(2):463-476.

Serecon Management Consulting Inc. 2005. Herbicide tolerant volunteer canola management in subsequent crops. Report prepared for the Canola Council of Canada. Calgary, AB. 49 pp. [Online] Available: http://www.canola-council.org/PDF/ht_canola_final.pdf [2006 Apr. 12].

Stenrod M, HE Heggen, RI Bolli and OM Eklo. 2008. Testing and comparison of three pesticide risk indicator models under Norwegian conditions - A case study in the Skuterud and Heiabekken catchments. Agriculture, Ecosystems & Environment. 123(1-3):15-29.

Tan S, RR Evans, ML Dahmer, BK Singh1 and DL Shaner. 2005. Imidazolinone-tolerant crops: history, current status and future. Pest Management Science. 61:246-257.

van Acker RC, AL Brûlé-Babel and LF Friesen. 2003. An environmental safety assessment of Roundup Ready® wheat: risks for direct seeding systems in western Canada. The Canadian Wheat Board. Prepared for the Plant Biosafety Office, Canadian Food Inspection Agengy.

Warwick SI, MJ Simard, A Legere, HJ Beckie, L Braun, B Zhu, P Mason, G Seguin-Swartz and CN Stewart. 2004. Hybridization between transgenic *Brassica napus* L. and its wild relatives: *Brassica rapa* L., *Raphanus raphanistrum* L., *Sinapis arvensis* L., and *Erucastrum gallicum* (Willd.) OE Schulz. Theoretical and Applied Genetics. 107(3):528-539.

3.0 Oilseed Rape Productivity in Western Europe and the Canadian Prairies

3.1 Introduction

In their beginning, GM crops were promoted as a solution to the world's food production problems, through substantially increased yields, especially in developing countries. However, nearly 15 years after introduction this prediction remains unfulfilled. The intention of most GM varieties is to facilitate more efficient weed (herbicide tolerance) and pest management (insecticide tolerance) and not to enhance yields explicitly. But by way of improving one of these factors, especially pest management, yields may be increased due to less damage from pest infestations. This concept is called yield protection by Monsanto. The most well known example of this situation is likely Bt cotton. In India, Bt cotton has increased yields by nearly 50% and substantially reduced the amount of pesticide applied against the cotton bollworm (James 2008). Another example, which is still in the research phase is late blight resistance in potato. Potato late blight caused by the oomycete *Phytophthora infestans* causes an estimated 10-15% reduction of global annual potato production (CIP 1995 as sited in Park et al. 2009). In Europe and the Netherlands in particular, GM has been suggested as a possible valuable solution to this problem (Park et al. 2009). Currently, there are no OSR varieties on the market that have been genetically modified specifically for higher grain yield. The great majority of GM OSR consists of HT varieties.

Although GM insecticide tolerant crops have provided notable increases in yield due to lessened damage by disease, this result is much less clear in herbicide tolerant (HT) crops, which make up the majority of transgenic crops cultivated (63%; James 2008). HT soy makes up the largest area of the area planted to GM crops, followed by HT maize, cotton and OSR. In an analysis of commercial yields of GM (Bt and HT) maize and (HT) soy in the United States, Gurian-Sherman (2009) concluded that although Bt maize has resulted in slight increases in yield (3-4%), there is no evidence of increased yields for HT soy over conventional soy.

3.1.1 Objectives

High variability in yields makes it difficult to distinguish the effect GM technology has had on yield in Canada, as well as predict the potential effect it may have in Europe. Chapter 3 aims to:

- Investigate yields of GM and non-GM (conventional) oilseed rape varieties in the Canadian Prairies using available data and past studies.
- Provide insight into factors stimulating the large differences in OSR yield between western Europe and Canada.

3.2 Data collection

Since OSR is a minor crop for the Netherlands, with 2500 hectares grown in 2008 (FAOstat), average yield was taken over four western European countries; namely: the Netherlands, Denmark, Germany and France to give a better representation of typical yields. Data was collected from FAOstat for these countries as well as Canada as a whole for consistency. For western Canada, yields were available from the Canola Council of Canada.

3.3 Effect of Herbicide Tolerance (HT) on Yield

Although transgenic cultivars were adopted rapidly, this was mainly due to improved efficiency and ease of weed control as opposed to superior yields (Mauro and McLachlan 2008). The first transgenic cultivars lacked the genetic background optimal for high yield compared to commercial cultivars at the time, but have since been improved to become at least as productive as conventional cultivars (Stringam et al. 2003). Nevertheless, in trials conducted in western Canada only 2 years after HT OSR entered the market, Stringam et al. (2003) found that GM cultivars tolerant to glyphosate, glyphosinate and bromoxynil had yields 10% higher than conventional cultivars. This is comparable to the 6% increase in yield referenced by Brookes and Barfoot (2009) in the United States for the early years of GM OSR, though it is unclear as to where this value comes from. Similarly, a survey carried out for the Canola Council of Canada in 2000 concluded that yields of HT OSR varieties were 10.7% higher than conventional varieties (Canola Council of Canada 2001). This report attributed the greater yields of HT cultivars to the improved genetic yield potential of these varieties, as well as to reduced competition from weeds.

In the UK, the BRIGHT program estimated costs of weed control in winter OSR to be less than conventional for glyphosate tolerant types and equal to or slightly greater than conventional for glufosinate tolerant systems (Sweet and Lutman 2006). Since yield losses due to weeds are usually limited in OSR, they concluded that the added cost for GM technology was not justified. For Canada however, these costs may be warranted. Although only one study (Harker et al. 2000) showed significant yield losses due to poor weed control, in the past producers were careful to grow OSR only in fields with relatively low weed pressure for this reason (R. van Acker, *personal communication*).

High weed pressure may partly explain higher yields in HT cultivars found by the Canola Council of Canada (2001) and in turn Brookes and Barfoot (2009), who used the Council of Canada study as the basis for their analysis. They applied the 10.7% increase in yield established in this study to yields from 1995 to 2003, to calculate the economic benefits of GM OSR. However, the Canola Council of Canada did not consider imidazolinone tolerant (Clearfield) varieties as transgenic or conventional in their study, and they were excluded. Thus, the Canola Council of Canada concluded an 11% superior yield for GM HT varieties over conventional varieties, excluding imidazolinone tolerant fields, not over imidazolinone tolerant and conventional fields as taken by Brookes and Barfoot. This is an important oversight, as Brookes and Barfoot note; the main alternative to GM varieties at the time was imidazolinone tolerant cultivars (making up 11% of the Canadian OSR crop, compared to 2% non-HT varieties in 2007). Furthermore, they use economic impacts from the 2008 National Center for Food and Agricultural Policy (NCFAP) report to determine farm level economic benefits from GM OSR in the United States. This report did not use any yield gains in determination of benefits associated with HT crops because weed management efficiency for the non-resistant crops was assumed to minimize pests. Although this report notes that this assumption is likely not completely true. Brookes and Barfoot (2009) used both the farm saving costs (costs saved from less herbicide use and tillage) as well as a 6% yield increase for the United States and 10.7% yield increase for Canada to determine farm level economic benefits. Ultimately, of the total on farm economic benefits stated from GM OSR in Canada from 1995 to 2007 87% of their estimate was due to yield gains. As a result, the large

economic benefits claimed would be reduced dramatically if lesser increases in yield were accounted for.

Contrary to others, Harker et al. (2000) found few differences in yields of HT and conventional systems, but concluded that HT OSR was advantageous in situations of higher weed pressure. Beckie et al. (2006) noted that HT OSR has allowed farmers to plant earlier compared with conventional systems due to the herbicide regime associated with the HT system. With conventional varieties, herbicides were required to be tilled into soil prior to sowing. Thus, if conservation tillage was adopted with HT OSR, sowing could occur slightly earlier. Improvements in yield have also been associated with conservation tillage as a result of increased plant-available water throughout the soil profile in spring (Johnston et al. 2002). Yields of each HT system change over time through conventional breeding and the release of new cultivars. In their review of Canada's experience with HT OSR, Beckie et al. (2006) concluded that there were no clear differences in yield between glyphosate, glyphosinate and imidazolinone tolerant varieties. Conversely, Brookes and Barfoot (2009) reported gains of 0-4% for glyphosate tolerant and 10-19% for glyphosinate varieties, similar to those found by Agriculture and Agri-Food Canada from 2001-2003. There are indications that glyphosate provides better weed control than glyphosinate, although this is not reflected by superior yield (Harker et al. 2000).

In recent years hybrid varieties have become more popular as growers have gained experience in their cultivation and are prepared to manage crops more intensively. As early as 1990, the first hybrid cultivar was approved in Canada, called "*Hyola 40*", a conventional variety. However, this cultivar was susceptible to blackleg fungi and its market success was short lived. In 1995 the first herbicide tolerant hybrids were released by Plant Genetic Systems (now Bayer CropScience), the glyphosinate tolerant hybrid cultivars RF1 and RF2 (MS1 x RF1, MS1 x RF2). These cultivars experienced relatively slow adoption because they did not show clear, large improvements in yield. In addition, the cost of hybrid seed was about twice the cost of open pollinated (OP) seed and the inability of producers to save seed discouraged the use of hybrids. It took about 15 years for hybrids to clearly demonstrate an advantage to producers over OP varieties; consequently HT technology was actually adopted before hybrid technology. Currently, 38 of the 47 varieties tested in the 2009 Prairie Canola Variety Trails were hybrid varieties and average yield advantages have been estimated at 15% and up to 30% for glyphosinate hybrids (Canola Council of Canada 2009; Beckie et al. 2006). Logically, glufosinate tolerant varieties may have higher yields due to a longer history of breeding hybrids at Bayer CropScience (which has the rights to the glufosinate tolerant trait), although this is not related to the HT trait.

Oilseed rape yields have been continuously rising over the past 20 years (Figure 3.1). To see the effect of the HT trait on yields, linear regression was performed for two time periods: from 1988 to 1997 and 1998 to 2008. Although HT OSR was first released to the market in 1995, from 1998 onward over 50% of OSR area grown was HT (approximately 62%; Beckie et al. 2006). Based on these two time periods, yields after 1997 are clearly higher than the previous period (student's t-test, $p=0.00041$). Of course these higher yields are not solely due to the effect of HT technology. Considering annual increase in yield between the two periods, the average annual increase for the first period was 0.03 +/- 0.13 tonnes/ha. For mainly HT varieties after 1998, annual increase was

slightly higher at 0.04 +/- 0.20 tonnes/ha, but this difference was not significant (F-test, p=0.009; Appendix 3.1). In addition if the record breaking yield in 2009 is excluded from this data set, rates of increase in yield would essentially be the same for the two time periods. Figure 3.1 also shows no evidence for a decrease in slope after the introduction of HT OSR, negating comments that conventional breeding efforts have been abandoned for research in biotechnology. These observations should be taken with some caution as yields are so variable that periods of 10 years, such as those used here are relatively short.

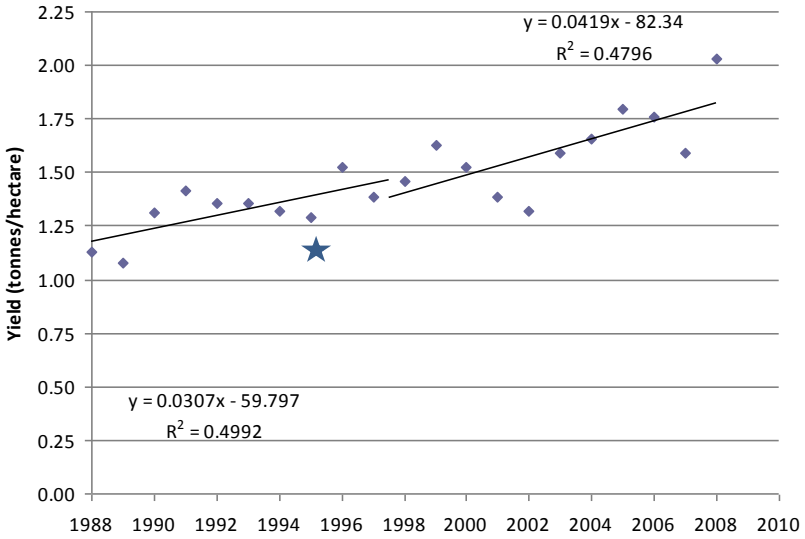


Figure 3.1. Annual average oilseed rape yields in the Canadian Prairie provinces of Alberta, Saskatchewan and Manitoba for 20 years, from 1988 onward. Two linear regression lines are fitted: the first from 1988 to 1997; the second from 1998 to 2008. The star indicates introduction of HT oilseed rape. All data from the Canola Council of Canada.

3.4 Western European and Canadian Prairie Oilseed Rape Yields

Despite claims of up to 10% higher yields in HT varieties, yields in western Europe remain approximately 120% of those in Canada from the early 90s onwards (more than double; Figure 3.2). For wheat this value was 217% higher, but only 20% higher for maize (Figure 3.3).

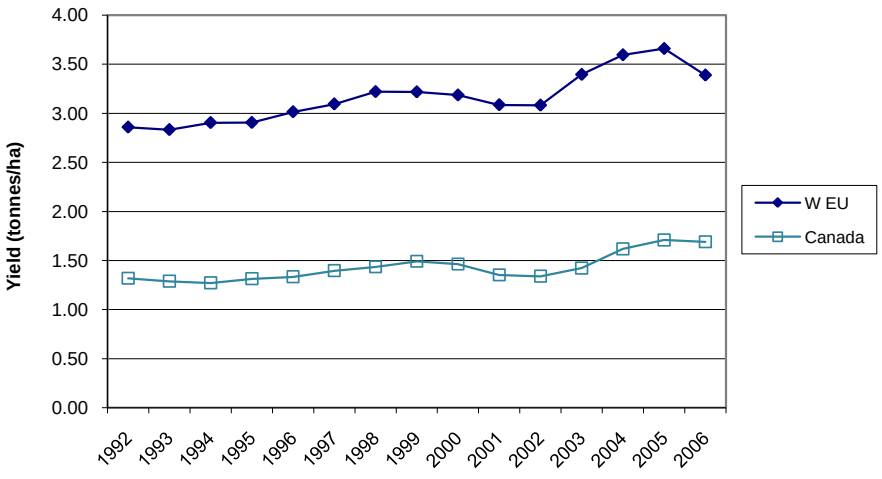


Figure 3.2. Three-year average oilseed rape yields in western Europe and Canada. Western EU includes the Netherlands, Germany, Denmark, and France. All data are from FAOstat. Note that Canada includes all of Canada, as FAOstat does not contain data fro the Prairies alone.

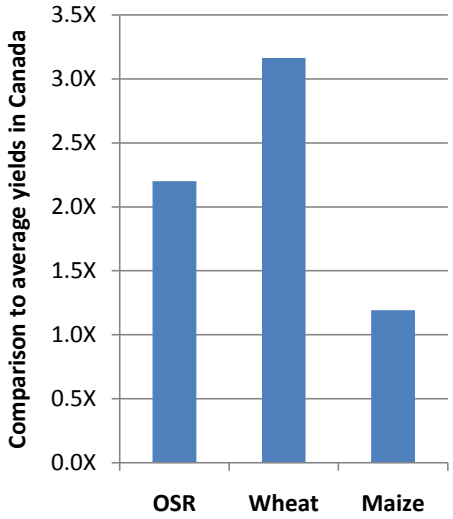


Figure 3.3. Average yield of several crops in western Europe compared to average yield in Canada from 1991-2007. Data from FAOstat.

Yields in the Canadian Prairies are generally slightly larger than those across the rest of the country. Average annual increase in yield was calculated for five year blocks from 1985 onward (Table 3.1). Since yields fluctuate considerably with annual conditions, average annual increase in yield was dependent on groupings of these blocks. However, some observations can still be made from these data. Average annual increases in yield for western Canada resemble those of Canada as a whole, and oddly variability for this region is also approximately the same as for all of Canada (Table 3.1). In addition to the fact that the Prairies cover a large geographic area (over 170 million hectares), this may be the result of more extreme climatic conditions, such as drought, in the Prairies compared to elsewhere in Canada. After the introduction of GM cultivars in 1995, there is no discernable change in average annual increase in yield (Table 3.1).

Interestingly, variabilities for western Europe are quite comparable to those for the Prairies and Canada. In Canada, this is likely due to a wide range of climatic conditions across such a large area, whereas in western Europe it is more likely due to differences in agronomic practice. The relatively large variability in recent years in western Europe may be accounted for by application of various environmental programs aimed at increasing sustainability of agriculture by reducing environmental burdens, for example limitations on nitrogen fertilizer applications (Peltonen-Sainio et al. 2009).

Table 3.1. Overview of annual increases in yields for western Europe, western Canada and all of Canada from 1985 to 2008. Annual increases are shown as averages +/- standard deviation, for time periods in five year blocks.

	Average Annual Increase in Yield (kg ha-1)				
	1985-1989	**1990-1994**	**1995-1999**	**2000-2004**	**2005-2008**
W EU	83.28 +/- 109	-54.08 +/- 144	70.86 +/- 167	158.26 +/- 411	-100.62 +/- 350
W Canada*	-6 +/- 182	40+/- 89	20 +/- 192	0 +/- 187	25 +/- 206
Canada	-2.18 +/- 187	30.90 +/- 113	65.34 +/- 161	-0.92 +/- 156	92.53 +/- 299

From FAOstat, 1985 to 2008. *From the Canola Council of Canada.

3.5 Why are Yields Higher in Europe?

Higher yields reported for HT OSR in North America are small relative to differences in yield with western Europe. The Canola Growers Guide (Canola Council of Canada) indicates that typical yields for the Prairies are about 1.2 tonnes/ha and also says that yields of the same order of those in Europe (3.0-4.5 tonnes/ha) are attainable, but does not give a reason behind the generally lower yields. Karamanos et al. (2005) achieved yields of 3.9 tonnes/ha with 165 kg N applied per hectare in the Aspen Parkland ecoregion, near Edmonton (53^{o} latitude). Of course in experimental situations yields are expected to be higher than in commercial agricultural practice. Despite slight drops in yield recently, yields in western Europe remain about twice those elsewhere, including GM production in the United States and Canada. This section explores the reasons behind these differences, including:

- Generally lower yield of spring type OSR grown in western Canada compared to the winter type in western Europe.
  Due to:
  - Genetic differences between cultivars, and
  - Longer growing season.
- Differences in inputs.
- Differences in agronomic conditions, climate, drought, etc.

3.5.1 Spring versus winter oilseed rape

Differences related to the spring and winter types of OSR are likely the most important factors in explaining the much higher yields in Europe over Canada. The most logical justification is the significantly longer growing season in winter OSR cultivation, despite slow growth rates during winter. In addition, genetic differences between winter and spring types likely plays a role.

3.5.1.1 Sowing date

Generally, early seeded crops outperform later seeded crops. For OSR, this is true for both spring and winter types, as well as within types. On the other hand in western Canada, this can depend on annual climatic conditions since the earlier crops are seeded, the more risk they will be killed by cold temperatures. Currently, winter OSR is not grown in western Canada in appreciable

quantities because it is seen as too risky by producers. Thus, early spring seeding is considered 'the earliest you can get on the field' by the Canola Council of Canada, and is ordinarily from late April to early May (Table 3.2). In particularly cold winters, or in some areas, late spring seeding occurring in late May might be the only option. In western Europe, generally winter OSR is sown from the middle of August in more northern areas including the Netherlands, to the middle of September in drier south-east regions of Germany (Christen et al. 1999). If spring OSR is cultivated in this area, it can be sown earlier than in the Prairies, normally in March and April when soil conditions become favourable.

Table 3.2. Oilseed rape yields of early versus normal sowing dates in several locations across Saskatchewan.

	Year	Early[1]	Normal[2]
		Yield (kg/ha)	
Whitewood	1998	1883	1571
Naicam	1998	2028	1833
Naicam	1999	2139	1967
Average		2017	1788

Data from the Canola Council of Canada, Canola Production Centre report.
[1]Late April to early May, [2]late May.

Performance trials in 2001 and 2002 of two winter OSR cultivars produced yields of 2.7 and 2.9 tonnes/ha, which is an improvement over spring types but less than yields of western Europe. Note that these trials (located in Elora and Ripley, Ontario) took place markedly further south than the major OSR producing areas of the Prairies.

3.5.1.2 Genetics

Since yield is a very complex trait, it is difficult to discern differences between spring and winter cultivars in terms of genetics, although it is recognized that winter cultivars generally out-yield spring cultivars. For this reason there is considerable interest in introgression of winter germplasm into spring *Brassica napus* L. This approach is also interesting to broaden the genetic base of OSR and potentially boost seed yields of hybrid cultivars. Breeding efforts of this nature have recently started in North America (Cargill & WARF 2009). Differences in genetic backgrounds and winter/spring types in varying climates can provide benefits. For instance, Australia uses early-flowering types because of drought problems in production areas (Diepenbrock 2000). It has also been speculated that the "double-low" OSR varieties, developed and traditionally grown in the Prairies, have been fighting to keep up with rapid advances in yield of varieties and hybrids with normal OSR fatty acid composition over the past 15 years (University of Alberta).

Since winter OSR is not grown in western Canada in appreciable quantities, the example of spring versus winter wheat can provide an idea of the effect of spring and winter types have on yield in the Prairies (Figure 3.4). Winter wheat had yields 0.39 tonnes/ha greater than spring wheat from 1985 to 2008 on average. In recent years, this difference has become even more pronounced at 0.89 tonnes/ha from 2000 to 2008 (Figure 3.4). Winter OSR is slightly less winter hardy than winter wheat, but responds to more N fertilizer (Canola Council of Canada). Although winter

OSR can withstand relatively low temperatures, winterkill most often occurs in spring when root reserves are low and frost heaving causes damage. There are two registered varieties of winter OSR in Canada, *Kronos* and *Baldur*. Both were developed in Europe (Ontario Canola Growers).

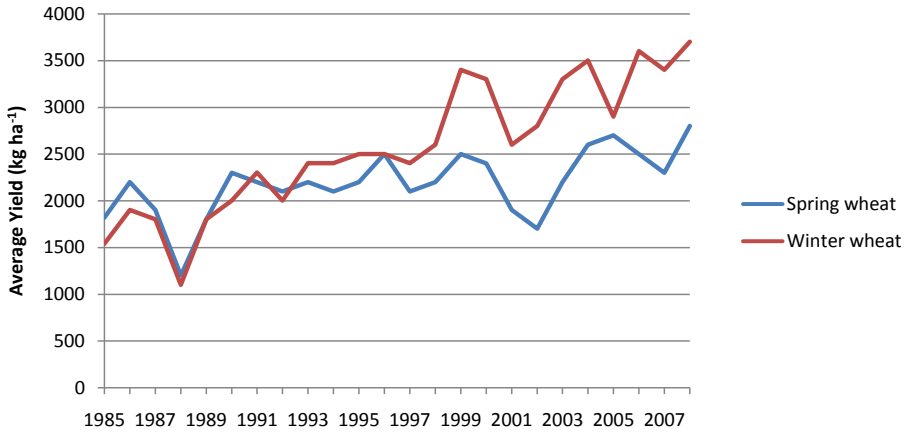


Figure 3.4. Average annual yield of spring and winter wheat in the Canadian prairies from 1985 to 2008. (CANSIM 2010).

3.5.2 Other Factors

3.5.2.1 Larger inputs

Differences in inputs and harvesting efficiency may play a role in large difference in yields between locations. The Government of Saskatchewan recommends fertilizer applications of 110 kg N/ha while rates of 180 kg N/ha are typical in the Netherlands (KWIN 2009). Pesticide inputs of 1.8 kg/ha and 0.95 kg/ha are typical in the Netherlands and western Canada, respectively.

3.5.2.2 Differences in agronomic conditions, climate, drought, etc.

Climatic conditions differ substantially between western Europe and the Prairies. Major constraints to production in the Prairies are harsh winters and short growing seasons, in contrast to the maritime climate of western Europe (Peltonen-Sainio et al. 2009). OSR is a cool-season crop, with optimal temperatures up to flowering of 13-22°C, however this is regularly not the case in western Canada (Canola Council of Canada). Heat stress during flowering limiting seed set and cooler temperatures throughout the majority of the growing season in Europe are believed to be important for higher yields (Wan et al. 2009). Sufficient precipitation in the Prairies can also be a problem during the growing season. The primary OSR producing area of Canada can be considered a semiarid climate, with crops often being exposed to both intermittent and terminal drought stress (Wan et al. 2009). Although, this region receives a relatively large amount of precipitation in June or July, this is hugely variable between locations and years (Figure 3.5; Canola Council of Canada). Yields in this region generally reflect seasonal precipitation patterns (Duggan et al. 2006). For breeders, the extreme variability in precipitation between seasons, both in timing and amounts, make development of breeding and crop management strategies for this region challenging (Wan et al. 2009).

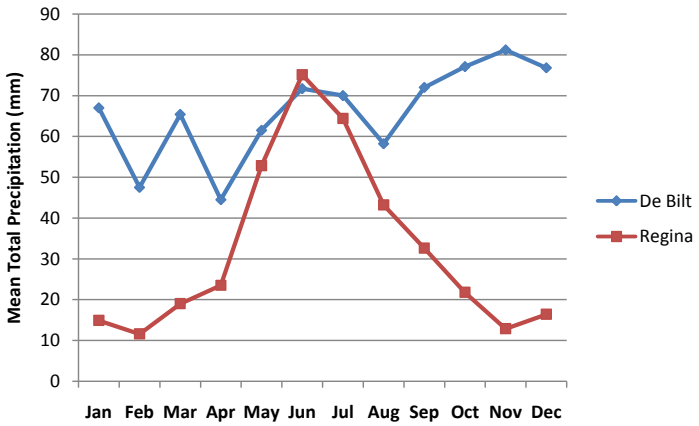


Figure 3.5. Mean total precipitation values for De Bilt, the Netherlands and Regina, Canada. All data from the World Meteorological Organization, World Weather Information Service. Data based on monthly averages for the 30 year period from 1971-2000 and includes rain and snow.

3.6 Conclusions

- Compared to herbicide use, studies noting the effect of GM HT OSR on yield are limited. Findings ranged from increases of 0% to 10%, however the latter was carried out by Monsanto (Harker et al. 2000; Stringam et al. 2003).
- This slight increase in productivity was mainly due to improved weed control as opposed to superior yields explicitly from the HT trait.
- It is difficult to distinguish yield gains as a result of improved genetics of new cultivars or from the reduced weed competition due to the HT trait; however it is apparent that the latter may be important when weed pressure is high, as in some cases in western Canada.
- Other factors which may have lead to increases in yield associated with the HT trait (operational increases) include:
    - HT OSR has allowed farmers to plant earlier compared with conventional systems due to the lack of requirement for soil-incorporation of herbicides prior to sowing.
    - Adoption of conservation tillage practices (including zero-tillage).

Canadian OSR yields have seen significant yield increases from the late 80s to 2009. Time periods both prior to and after mass adoption of GM varieties showed constant annual increases in yield. Average rate of this increase has not changed significantly due to production of HT varieties. Adoption of hybrid cultivars has also been a major factor in increased yields since 2003.

Yields in western Europe have remained approximately twice as large as those in Canada primarily due to the lower yield of spring OSR grown in western Canada compared to mainly winter OSR cultivation in western Europe. Producers in the Prairies may be able to grow winter OSR in future when drought stress-tolerant cultivars become available. Currently, there are efforts in Canada and Australia to develop drought-tolerant spring types (Wan et al. 2009). Other reasons for differences in yield between locations are larger inputs in western Europe, differences in climate, agronomic practice and the occurrence of drought in western Canada.

3.7 References

CANSIM database, Statistics Canada. Estimated areas, yield, production and average farm price of principal field crops, in metric units, annual, 1908 to 2010. Table 001-0010.

Canola Council of Canada. 2009. 2009 Prairie canola variety trails test results. Available online: http://www.canola-council.org/uploads/PCVT%202009%20for%20web.pdf.

Christen O, E Evans, C Nielsson and C Haldrup. 1999. Oilseed rape cropping systems in NW Europe. Proceedings of the 10th International Rapeseed Congress. Canberra, Australia.

Government of Saskatchewan, Canola Production. 2008. Available online: http://www.agriculture.gov.sk.ca/Default.aspx?DN=a866a31e-266f-49aa-a3db-44f31dda65ea.

Duggan BL and DB Fowler. 2006. Yield structure and kernel potential of winter wheat on the Canadian Prairies. Crop Science. 46:1479-1487.

Gurian-Sherman D. 2009. Failure to yield: evaluating the performance of genetically engineered crops. Union of Concerned Scientists (UCS) Food and Environmental Program Publication. April 2009.

Harker KN, RE Blackshaw, KJ Kirkland, DA Derksen and D Wall. 2000. Herbicide-tolerant canola: weed control and yield comparisons in western Canada. Canadian Journal of Plant Science. 80:647-654.

KWIN. 2009. Praktijkonderzoek Plant & Omgeving B.V. (PPO) publication 383: *Akkerbouw en Vollegrondsgroenteteelt 2009 Kwantitatieve Informatie* (KWIN).

James C. 2008. Global status of commercialized biotech/GM crops: 2008. ISAAA Brief 39.

Johnston AM, DL Tanaka, PR Miller, SA Brandt, DC Nielsen, GP Lafond and NR Riveland. 2002. Oilseed crops for semiarid cropping systems in the northern Great Plains. Agronomy Journal. 94:231-240.

Karamanos RE, TB Goh and DP Poisson. 2005. Nitrogen, phosphorus, and sulfur fertility of hybrid canola. Journal of Plant Nutrition. 28:1145-1161.

Mauro, IJ and SM McLachlan. 2008. Farmer knowledge and risk analysis: postrelease evaluation of herbicide-tolerant canola in western canada. Risk Analysis. 28(2):463-476.

Park TH, VGAA Vleeshouwers, E Jacobsen, E van der Vossen and RGF Visser. 2009. Molecular breeding for resistance to *Phytophthora infestans* (Mont.) de Bary in potato (*Solanum tuberosum* L.): a perspective of cisgenesis. Plant Breeding. 128:109-117.

Peltonen-Sainio P, Hakala K, Jauhiainen L and K Ruosteenoja. 2009. Comparing regional risks in producing turnip rape and oilseed rape: impacts of climate change and breeding. Acta Agriculturae Scandinavica Section B. Soil and Plant Science. 59:129-138.

Pray CE, J Huang, R Hu and S Rozelle. 2002. Five years of Bt cotton in China: the benefits continue. The Plant Journal. 31(4):423-430.

University of Alberta. 2005. Review of University of Alberta canola breeding program: a review and assessment of canola breeding at the University of Alberta. Prepared by BrassicaCorp. Ltd. and S.J. Campbell Investments Ltd.

Wan J, R Griffiths, J Ying, P McCourt and Y Huang. 2009. Development of drought-tolerant canola (*Brassica napus* L.) through genetic modulation of ABA-mediated stomatal responses. Crop Science. 49:1539-1554.

World Meteorological Organization, World Weather Information Service. Available online: http://worldweather.wmo.int/.

4.0 Comparing Whole System Sustainability using Total Factor Productivity (TFP)

4.1 Introduction

Thus far this report has focused on crop protection and productivity aspects of agro-ecological sustainability. This chapter aims to integrate these aspects of sustainability with other environmental and economic aspects to provide an overview of whole system sustainability. There are several methods which have been used to holistically assess agricultural sustainability, the most common of which are the ecological footprint and the environmental sustainability index (Siche et al. 2008). The ecological footprint uses a matrix to calculate the necessary land area for the production and maintenance of goods and services consumed by a given community. The environmental sustainability index (ESI) considers five dimensions: i) environmental systems, ii) critical levels of pollution, iii) human vulnerability, iv) social and institutional capacity, and v) global stewardship. This method was developed for the purpose of comparing the sustainability of countries, but is complex and quite labourious to calculate. The dimensions listed consist of 146 variables, one of those being the environmental footprint.

Another method, used by Glendining et al. (2009), is the total factor productivity (TFP) approach based on comprehensive economic analysis. This method was applied to assess the environmental and economic sustainability of several arable crop and livestock systems in the United Kingdom with the aim of determining the optimum level of inputs for each system that reduced environmental pollution as much as possible while minimizing consumption of resources, and maintaining farm income at as high a level as possible. Given that levels of food production should at least remain constant (or increase), when inputs were reduced more land was needed to produce the same amount of food. Interestingly, this study found that due to this cost of additional land, extensification of agricultural systems caused an increase in the financial cost of the system as a whole. Therefore, they concluded that high input agriculture was more sustainable, although at slightly lower levels than those currently practiced in the UK.

4.1.1 What is Total Factor Productivity (TFP)?

Total-factor productivity (TFP) is an economics term that expresses the output produced from the use of a given quantity of inputs as a ratio. TFP can be applied to many systems to provide a numerical measure of sustainability. For agricultural systems, there are many inputs: land, seed, labour, machinery, fertilizers and crop protection agents. The primary outputs on an arable farm are crop produce. For the environmental dimension of sustainability, costs are associated with degradation of land and pollution, for example nitrate leaching, soil erosion, and polluting of neighbouring land and water resources by crop protection agents. These environmental costs are treated as additional inputs in TFP calculations appearing in the denominator of Equation 1. The alternative of including them as output costs might have led to negative values for the indices – a less convenient option.

In order to combine all components of the system into a single index value, such as TFP, some form of weighting must be used. The most widely used measure of value is monetary value, so normally all components are weighted according to price. Finally, all weighted components of

outputs and inputs are summed and the system is considered sustainable if the value of the outputs exceeded those of the inputs. In other words, if the value of Equation 1 is greater than one, and remains so for a number of years the system is sustainable.

Equation 1. Calculation of the total factor productivity (TFP) index.

$$TFP = \frac{\sum_{j=1}^{m} P_j Q_j}{\sum_{i=1}^{n} W_i X_i}$$

where W_i is the cost of each of n input factors used at rate X_i, and P_j is the value of each of m outputs yielding a quantity Q_j each.

Prices for most inputs and outputs of an agricultural system are relatively easily obtained, however environmental costs of a system are much more difficult to evaluate. For consistency, it is necessary to assign these costs a monetary value as well, despite the inherent flaws of doing so. Methodology to determine values for these costs are described in Section 4.4.1.

4.1.2 Objectives

Chapter 4 of this report will focus on the following objectives:

- To integrate crop protection (Chapter 2) and productivity (Chapter 3) aspects of agro-ecological sustainability into an overview of whole system sustainability and to determine the relative importance of these aspects in sustainability of the systems.
- The TFP approach of Glendining et al. (2009; hereafter referred to as Glendining) will be used to achieve a picture of whole system sustainability for OSR cultivation and to compare sustainability of the various systems in the Netherlands and western Canada.
- Focus will be on GM OSR versus conventional OSR in Canada and effects of adoption of zero-tillage practices associated with GM OSR will be investigated.

4.2 Methods

TFP indices were calculated for cultivation of OSR in the Netherlands and western Canada. Since OSR was included in Glendining's study, many costs such as those for environmental processes could be taken directly from their work. Necessary data for the Netherlands was obtained from the *Praktijkonderzoek Plant and Omgeving B.V. (PPO) publication 301: Akkerbouw en Vollegrondsgroenteteelt 2002 Kwantitatieve Informatie* (KWIN). Data from Canada was obtained from various sources outlined in Section 4.2.3.

4.2.1 Summary of Glendining et al. 2009 Methods

With the aim of determining application rates of inputs which maximized sustainability, Glendining modeled crop yield related to nitrogen application rates using the Quadmod system (ten Berge et al. 2000). In order to assess sustainability of agriculture, it is necessary to take environmental impacts, often termed externalities, into consideration. The TFP approach accounted for these impacts by estimating their financial cost. The following provides a brief overview of the methods used to estimate costs of environmental impacts namely: biocide use, nutrient losses and greenhouse gas (GHG) emissions.

4.2.1.1 Major Environmental Cost Categories and Assumptions

i) Crop protection agents

- Economic cost and environmental cost of producing these chemicals
- Environmental cost associated with usage:
    - Sum of the costs of removing the compounds from drinking water and the cost of the loss of abundance and diversity of wildlife.
    - Costs associated with loss of biodiversity were estimated by Pretty et al. (2000) using costs to restore species and habitats under the Biodiversity Action Plans (BAPs) of the UK.

ii) Nutrient losses

- Were calculated solely based on current, typical nitrogen fertilizer application rates (for nitrogen losses) and OSR crop requirements (for phosphorus losses; see Appendix 4.1).
- Only nitrogen and phosphorus were considered.
    - Costs summed from loss of biodiversity and habitat and removal of nitrate and phosphate from drinking water. Ammonia was not included.

iii) Greenhouse gases (GHGs)

- Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) produced during agricultural production and manufacture of inputs used in production.
- Environmental cost of GHGs used were from Atkinson et al. (2004; Table 4.1).

Table 4.1. Cost to the environment of greenhouse gases used in Glendining et al. (2009).

GHG	Units	Cost (US$)
CO_2	tonne C	115.5
CH_4	tonne CH4	660
N_2O	tonne N2O	9220.2

Values represent estimates from Atkinson et al. (2004).

iv) Loss of Ecosystem Services

The cost of bringing land into crop production was taken as a cost to the environment. Glendining took agricultural land area into account because, although a less intensive system may pollute less on a per hectare basis, it requires more land area to produce the same amount of food. Thus, extra land needed to produce food with less pollution has a cost associated with it. The more ecosystem services provided by the land used, the greater its value per hectare. This was relevant in their study as they looked at effects of extensification of agriculture.

Land use was converted to financial values based on the concept of ecosystem services outlined by Constanza et al. (1997) (Table A-12).

- Value of ecosystem services lost by conversion of non-agricultural land (taken as the state of the land if it was undisturbed) to cropland did not include value of food and fibre production for a given ecosystem. This benefit was attributed to crop production in Glendining's analysis and as a result was included elsewhere.
- The value of renting or owning land was also included as an on farm cost.

Indirect environmental costs associated with chemical and machinery production are more difficult to estimate and were taken from the environmental life-cycle assessment (LCA) analyses of Williams et al. (2006) for several commodities produced within UK agriculture. In LCA, the inputs for an individual component are traced back along its production system and include steps prior to the farm but exclude everything after the product is sold and leaves the farm. For example, iron ore mining and steel production are attributed to the annual use of a tractor. In this way, financial cost of a product was accounted for as on farm costs and environmental costs were determined through LCA. This does not include transport, processing, packaging and distribution of farm produce. For the production of agricultural chemicals and fertilizers, direct costs were not included because they were included in the price paid by the farmer and appear in the denominator of the TFP index. Environmental costs of manufacturing these products were included.

4.2.2 Current Methods

Generally, the methods of Glendining were followed with a few notable changes. First, since the aim of their study was to optimize application rates of inputs to achieve maximum sustainability, Glendining calculated TFP over hypothetical increases in crop yields. To compare current sustainability of the systems in the present analysis, actual yields for each location were used. Glendining also expressed TFP on the basis of land area (per hectare). The concept of sustainability presupposes that an agricultural system should at least maintain current levels of food production without environment degradation. Therefore, productivity should be taken into account and in this analysis; TFP was calculated per tonne of produce to make this explicit. Furthermore, without consideration of productivity, extensive systems may tend to consistently appear more sustainable than intensive systems. All costs and values are per annum and represent those for the 2008/2009 season (unless otherwise stated).

The glyphosate tolerant system was chosen to represent all GM systems in Canada. Of the three major HT OSR varieties grown, glyphosate tolerant cultivars make up over 50% of the cultivated area (including imidazolinone tolerant varieties; Leeson et al. 2006). This system was assumed to be zero-tillage, while conventional systems were considered plough-based.

Lastly, all monetary values presented are in US dollars ($) unless otherwise stated. Currency conversions were as follows: 1 Euro = 1.48 US$, 1 British pound = 1.65 US$ and 1 Canadian dollar = 0.95 US$. Important changes to the methods of Glendining are mentioned below. Appendix 4.1 contains details of assumptions and methods used.

i) <u>On Farm Costs to Growers</u>

Values such as returns per tonne of produce can be easily obtained. Other values including cost of seed are more difficult to acquire. For comparison purposes, the same per unit price was used for all costs to farmers including: labour, fertilizer, energy, etc. The only value which differed between Dutch and Canadian operations was land rental value, which was much higher in the Netherlands. Also for GM cultivation, an additional 35 US$/ha technology fee was added to cost of seed (R. van Acker, *personal communication*).

ii) Farm Revenue

Revenue per tonne of produce was set at 400 US$/tonne for the Netherlands and Canada (from KWIN 2009). Returns per tonne of produce were available for Canada, but again for comparison purposes, the same market price was used for all situations. Selling prices fluctuate with global markets, although in general differences between selling price for Dutch and Canadian farmers are not substantial. For the 2008/2009 season, average OSR selling price was 407 US$/tonne in Canada.

iii) Crop Protection Agents Cost to Grower

This is the cost of the biocide materials themselves. These costs can be difficult to obtain from retailers. Glendining used number of biocide products applied to OSR (8.1 in 2004 excluding seed treatment) and cost per product based on standard agronomic publications (Nix 2005 and ABC 2005). As they point out themselves, this is an oversimplification, due to the large range in the costs of different crop protection products. In the present study, these simplifications were not necessary and costs published in the KWIN (2009) were used, so costs of individual biocides could be taken into account. These costs were put directly into TFP calculations for the Netherlands. Costs for Canada were not available directly and were calculated from values for the Netherlands as the weighted average cost for each class of biocide (Table 4.2). Seed treatments were included in cost of seed.

Table 4.2. Cost of crop protection agent types calculated from the KWIN (2009) for use in Canadian OSR TFP calculations.

	Weighted Average Cost (US$/kg a.i.)
Herbicides	157.13
Insecticides	1600.00
Fungicides	238.98

iv) Crop Protection Agents Cost to Environment

For use of biocide and fertilizer, two types of costs of environmental impacts were included: those from direct effects of the inputs themselves on the environment and those indirectly from the operations required to apply these inputs.

Biocide pollution

Cost of the direct effect of biocides on soil and aquatic biology. Glendining estimated these costs at 16.30 US$/kg of a.i. (£9.88 per kg a.i.). This value was used for all systems and represented costs of biodiversity loss and removal of biocide residues from drinking water determined by Pretty et al. (2005). Biodiversity can be difficult to assess and even more difficult to attribute financial values to. Pretty et al. (2005) used costs of restoring species and habitats under the Biodiversity Action Plans (BAPs) of the UK to estimate costs of wildlife and habitat losses. For species and habitats for which agriculture was identified as one of the causal agents, they assumed that 50% of the costs of actions to protect and restore biodiversity was due to the use of crop protection agents. Environmental impact associated with energy required to apply biocides was accounted for elsewhere and seed treatments were not included. Details of methods and their references are included in Appendix 4.1.

Application of biocide

The costs associated with biocide application, mainly accounted for by burning of diesel. Glendining used an average number of spray operations for biocides of 5 (number of times farmer goes on the field). This was sufficient for their purposes as few applications are needed in OSR relative to other crops investigated, such as potato. To include the specific quantity of biocide applied to each system (of interest for the present study) in our analysis, it was necessary to adjust number of spray operations for quantity of biocide applied. Number of spray operations required was calculated using a maximum rate of 0.35 kg a.i./ha per individual operations.

v) Fertilizer Costs to Environment

The approach for quantifying environmental impacts of fertilizer use was similar to that for biocides. Direct effects of fertilizer on the environment included nitrogen and phosphorus loss from fields and emission of GHGs directly from fertilizer. These costs were dependent on rate of fertilizer application and OSR crop requirements (for phosphorus). Costs of applying fertilizer were also accounted for.

vi) Labour

Although labour costs were held constant between the two locations, lower costs were included in systems using zero-tillage, namely GM cultivation. There are few reports in the literature quantifying the value of labour saved by adoption of zero-tillage practices compared to plough-based (conventional) tillage in OSR. As a result, some calculations were made to estimate savings in labour costs (Table A-5). Calculations assumed a wage of 15 US$/hour per hour (approximately minimum wage plus 50%). The resulting estimation of value of labour saved using zero-tillage was 15.81 US$/ha, similar to average savings of 6-9$/ha found by Zentner et al. (1992).

vii) Subsidies

Glendining found that subsidies played an important role in maintaining profitability for farmers. Although this is true for both the Netherlands and Canada, subsidies were not included here as the focus was on sustainability as opposed to profitability. Subsidies also vary drastically, over time and between countries. Generally, government subsidies and program payments are substantially larger in the Netherlands than those in Canada.

viii) Loss of ecosystem services

Similar to Glendining, cost of land was included in TFP analyses to account for the contrast between relatively intensive agriculture in the Netherlands and extensive practices in Canada. Land area was taken into account as the cost inherent in the conversion of non-agricultural land (taken as the state of the land if it was undisturbed) to cropland. For the Netherlands, the undisturbed state of the land was assumed to be temperate forest and the resulting cost associated with the conversion to cropland was 154 US$/ha(/annum). In the Prairies, land was considered to be grassland prior to conversion to agriculture with a cost of 92 US$/ha associated with this change.

4.2.3 Data Sources

The majority of costs, both to the farmer and to the environment, were taken from Glendining as outlined in the previous section and in Appendix 4.1. However, quantities of agricultural inputs and crop yields for each location were obtained from different sources. For the Netherlands, these values were obtained from the KWIN (2009). In Canada, there are no standard publications for inputs on a per hectare basis and various sources were required (Table 4.3). As investigated in detail in Chapter 3, there is some evidence to support slightly higher yields of GM OSR varieties over conventional. A conservative estimate of 5% higher yields was used in this analysis. All inputs for TFP were per hectare, but outputs (TFP indices) were expressed per tonne of produce to explicitly include productivity in our concept of sustainability.

Table 4.3. Inputs used in determination of total factor productivity (TFP) for OSR production in the Netherlands and western Canada.

	Netherlands conventional	Western Canada conventional	Western Canada GM	Source for Western Canada
Inputs				
Fertilizer N applied (kg N/ha)	180	110	110	J. Leeson, *personal communication*
Total biocides applied (kg active ingredient/ha)	1.78	0.88	1.12	2001, 2002, 2003 Prairie Weed Management surveys
Tillage method	Plough-based	Plough-based	Direct drilled/ zero-tillage	Various
Seed cost (US$/ha)	75	75	110	R. van Acker, *personal communication*
Output				
Yield (tonnes/ha)	4.0	1.8*	1.9	Statistics Canada. Cereals and Oilseeds Review - December 2009

All data for the Netherlands from the KWIN 2009.

*Yield of conventional varieties in western Canada estimated at 5% less than 1.9 tonnes/ha reported by Statistics Canada for OSR in 2009.

4.3 Results

Despite higher total OSR on farm production costs in the Netherlands than the Prairies, on farm costs were lower per tonne of produce than those in the Prairies (Figure 4.1). Within the two Prairie systems, GM OSR had on farm costs 20$/tonne higher than conventional, mainly attributable to the cost of additional crop protection agents. Conclusions related to cost of specific products cannot be drawn, since retail cost of biocide materials in Canada were estimated from those provided in the KWIN (Table 4.2). After labour and machinery costs, the largest on farm investments were in biocide and fertilizer purchases which comprised approximately 35% of total on farm costs for the Netherlands and GM OSR and 25% for conventional OSR in Canada (Figure 4.2). The methods of Glendining resulted in relatively low costs to the environment ranging from 18 – 14% of total costs per tonne (Figure 4.1).

TFP indices including costs to the environment fell below 1 for all systems indicating potentially unsustainable agro-ecological systems (Figure 4.3). When considering on farm costs only (excluding costs to the environment), TFP was greater than 1 for the Netherlands, but not for either system in Canada. This does not imply that Prairie OSR growers do not make any profit. In this analysis subsidies and program payments were not included; therefore TFP values (on farm and total TFP) are representative of environmental sustainability as opposed to profitability. Also, the differences between relative TFP values of the systems analyzed are a much better indication of sustainability than absolute values. Thus, a TFP index of 0.90 for OSR production in the Netherlands was more sustainable than that indicated by TFP indices of 0.58 for both GM and conventional production in Canada.

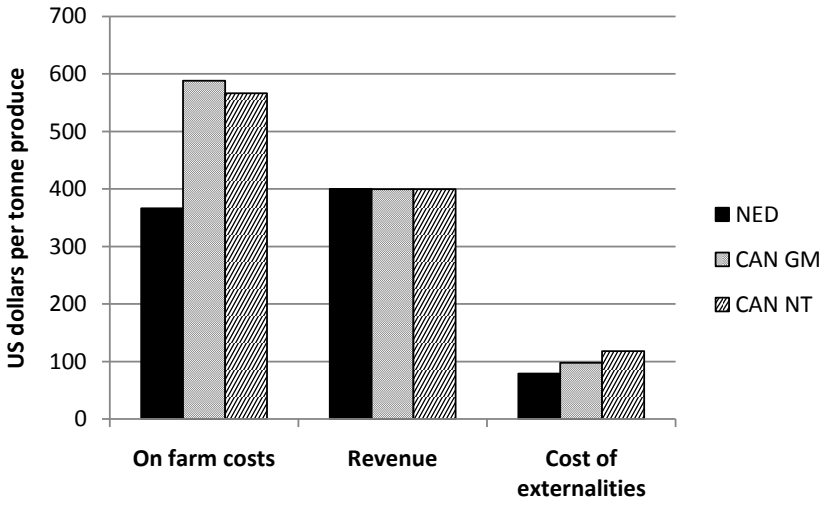


Figure 4.1. Components of total factor productivity (TFP) for oilseed rape cultivation in the Netherlands (NED), and conventional (CAN NT) and glyphosate tolerant systems in Canada (CAN GM). All values are presented on a per tonne basis.

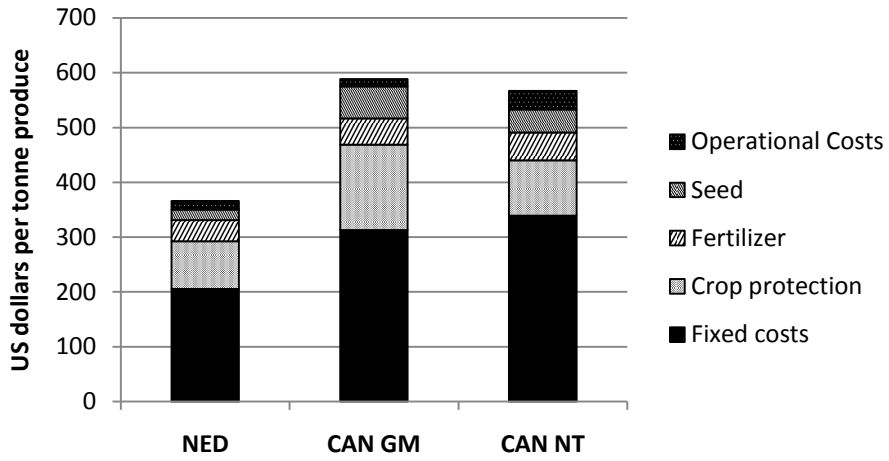


Figure 4.2. Breakdown of total on farm costs for oilseed rape cultivation in the Netherlands (NED), and conventional (CAN NT) and glyphosate tolerant systems in Canada (CAN GM). Fixed costs are made up of: labour and machinery costs, land rental, and general overheads. Fertilizer and biocide costs include both the cost of the products themselves as well as costs of application. Operational costs are mainly the cost of diesel for cultivation, harvest and post-harvest activities. All values are presented on a per tonne basis.

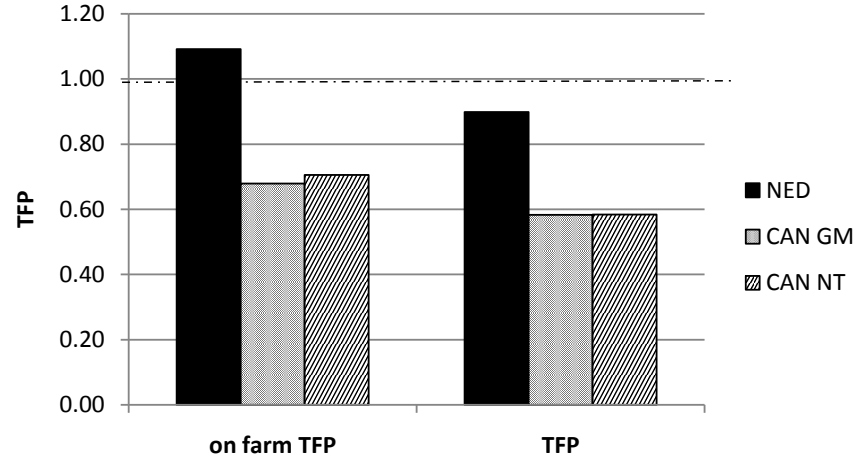


Figure 4.3. On farm total factor productivity (TFP) and total TFP including costs to the environment for OSR in the Netherlands (NED), and conventional (CAN NT) and glyphosate tolerant systems in Canada (CAN GM). Dashed line indicates a sustainable system.

Comparisons between the Netherlands and Canada were difficult due to large variation between agricultural systems, but Prairie systems could be compared more closely. For these systems, conventional and GM OSR cultivation were determined to have similar sustainability. Despite 5% larger yields in GM systems, conventional OSR had a slightly higher on farm TFP than GM. Total TFP indices were the same for both systems, suggesting that GM production is associated with lesser costs to the environment. These findings do not support the rapid adoption of GM OSR by Prairie farmers, which suggests greater net profits (on farm TFP) from GM systems.

Brookes and Barfoot (2009) stated that production costs (excluding technology fee) of GM OSR systems have been about 30$/ha lower than conventional OSR in Canada mainly due to reduced expenditure on herbicides and some savings in fuel and labour. The present study estimated savings in fuel and labour at approximately 50$/ha, but these savings were more than offset by greater herbicide use (Chapter 2). With an increase in the technology fee after 2002, Brookes and

Barfoot (2009) estimated total production costs to be similar for both systems. Our estimates indicated that if herbicide use levels were in fact the same, GM OSR provided savings of 15$/ha.

Potential savings in labour, machine operation and machine overheads were estimated by Zentner et al. (1992) at 5-10$/ha, while our results suggested a reduction in labour costs of 50$/ha would be required to decrease costs enough to reach a TFP value equivalent to that of conventional OSR. In the UK, the BRIGHT programme estimated costs of weed control in winter OSR to be less than conventional for glyphosate tolerant types and equal to or slightly greater than conventional for glufosinate tolerant systems (Sweet and Lutman 2006). Since yield losses due to weeds are usually limited in UK OSR cultivation, they concluded that the added costs of GM were not justified. In Canada on the other hand, poor weed control has resulted in yield losses in spring OSR. As a result, this added cost may be warranted in Canada, but this issue could not be addressed in this study, as in general conventional OSR producers are careful to grow OSR only in fields with relatively low weed pressure (Beckie et al. 2006).

4.3.1 Costs to the Environment

The values allocated to the various environmental costs resulted in a relatively small contribution to total costs. Of these costs, loss of ecosystem services was the largest contributor, followed by GHG emissions, nutrient loss and impacts of biocide use (Figure 4.4). Loss of ecosystem services is the cost inherent in the conversion of natural land to cropland and was 39$/tonne for the Netherlands, 48$/tonne for GM and 51$/tonne for conventional OSR in Canada. This relatively large cost is one reason Glendining's analysis concluded that area of land under cultivation was the decisive component in determining sustainability, as opposed to other factors such as nutrient losses or GHG emissions. In addition, since total environmental costs of OSR are so low the initial conversion of non-agricultural land to cropland comprised much of the total environment cost of OSR production compared to other crops investigated by Glendining.

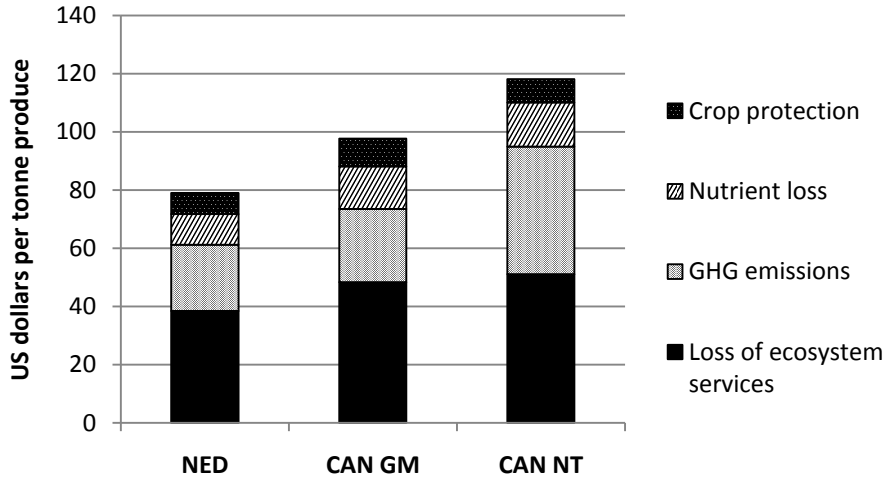


Figure 4.4. Distribution of major costs to the environment for OSR cultivation for the Netherlands (NED), and conventional (CAN NT) and glyphosate tolerant systems in Canada (CAN GM).

Total costs to the environment were larger for Canadian systems than the Netherlands per tonne of produce. For conventional cultivation in Canada, GHG emissions were notably higher than the

other two systems (44$/tonne for conventional versus 25 and 23$/tonne for GM and the Netherlands respectively). The majority of GHG emissions were accredited to burning diesel for operation of machinery for tillage, harvesting and application of fertilizer and biocide. The remainder of emissions were nitrous oxide (N_2O) solely due to N fertilizer applications. The comparably large difference between conventional and GM systems suggested that quantity of GHGs emitted in tilling operations were greater than those emitted during application of extra herbicides in zero-till systems. The methods used did not account for increased levels of organic carbon sequestered in soil associated with conservation tillage. Although, lower intensity tillage reduces oxidation of soil organic carbon and subsequent release as carbon dioxide, soil organic carbon levels fluctuate over long time periods and with management (Follet 2001). Effects of the various tillage practices will be discussed in further detail in the next section.

High yields in the Netherlands lead to slightly lower environmental costs per tonne of produce for nutrient loss and pollution from crop protection agents, indicating greater use efficiency of inputs than Canadian systems. Particularly for fertilizer application, much higher application rates in the Netherlands were compensated for by higher yields, such that nutrient loss per tonne was lower for the Netherlands than in Canada. Costs associated with the environmental impact of biocides were consistent at about 8$/tonne for all systems. This result was comparable to that found using the EIQ approach in Chapter 2, as environmental impact (*field* EIQ) for the Netherlands was less than that of the Prairie systems when considered per tonne of produce. Finally, since costs from the environmental impact of crop protection agents comprised such a small portion of total environmental costs, cost of applying additional biocide using GM varieties was negligible for environmental sustainability using this method.

Although, environmental costs make up a small proportion of the whole it is important to keep in mind that these costs were based on financial values assigned to various environmental resources, many of which are difficult to assess and are associated with considerable uncertainty. For example, quantifying the value of land by its ecosystem services is associated with considerable ambiguity, as these values are averages for biomes across the world and included a value for landscape, which is rather subjective due to a component of societal value. Despite the uncertainty associated with environmental costs, the best available financial costs were used in our analysis and methodology aimed to be objective and transparent (Pretty et al. 2005; Atkinson et al. 2004, etc.).

4.3.2 Effects of Tillage Practices

Although the adoption of conservation tillage was underway before the introduction of HT OSR in Canada, these new varieties facilitated further adoption of zero and reduced tillage practices (Marvier and van Acker 2005). By the early 2000s, figures for proportion of growers using zero till systems were 35% of glyphosate tolerant, 45% of glufosinate tolerant and 35% of imidazolinone tolerant OSR in the Prairies. In the TFP analyses of Canadian OSR, differences in cost of agronomic practices (operational costs) were mainly due to plough-based tillage in conventional OSR compared to zero-tillage in GM OSR. Costs of plough-based tillage practices were estimated to be 4.5 times greater than zero-till, with these costs being directly to the farmer.

With zero-tillage or direct seeding, herbicides are used instead of tillage to control weeds. Accordingly, investment in biocides was higher in GM OSR and these costs out-weighed those for tillage. More specifically, 55$/tonne for herbicide products not recovered by savings of 20$/tonne in diesel and 15$/tonne in labour saved by the grower for tillage practices. If environmental costs are included, GHG emissions from zero tillage operations reduced costs by an additional 18$/tonne (Figure 4.5). For reduced tillage these returns decreased to approximately 10$/tonne.

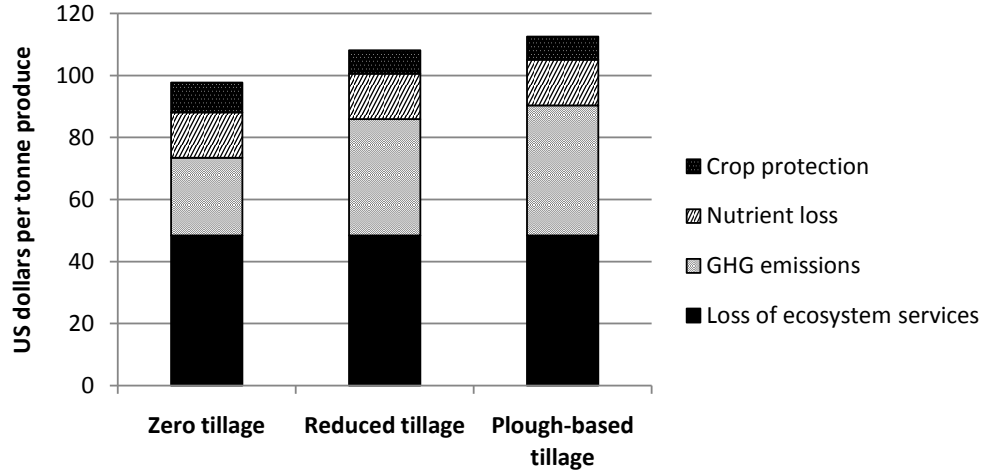


Figure 4.5. Costs to the environment of glyphosate tolerant (GM) OSR cultivation in Canada under zero, reduced and plough-based tillage.

Costs to the environment focused on impacts to the wider environment, mainly due to the use of machinery and fossil fuel combustion. Advantages of zero-tillage to the local environment such as soil moisture conservation and reduced erosion were not included. In western Canada improved soil moisture conservation is especially important as drought occurs frequently. Therefore it is possible that cost savings were underestimated, however arguably these costs would be accounted for in better crop yield over several years. Finally, this analysis assumed that all tillage and harrowing was performed independent of other operations, such as seeding, herbicide or fertilizer application and cost savings would be reduced if these practices occurred together with another operation.

4.3.3 Energy use

Nitrogen fertilizer is the most important input in terms of energy consumption for arable systems. Williams et al. (2006) estimated that fertilizer manufacture accounted for 58% of the total energy used to produce bread wheat, with biocide manufacture accounting for another 5%. In our analysis, energy use in manufacture and transport of fertilizer, biocides and machinery was not included separately as it was accounted for in their cost. Using the values of Williams et al. (2006), direct and indirect energy investment for the various OSR systems could be determined (Figure 4.6).

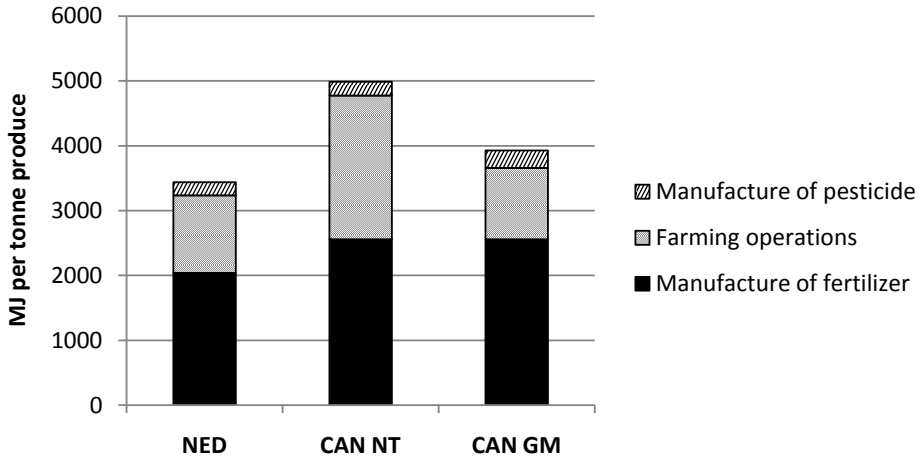


Figure 4.6. Direct and indirect energy input for oilseed rape cultivation in the Netherlands (NED), and conventional (CAN NT) and glyphosate tolerant systems in Canada (CAN GM). Farming operations include: soil cultivation, harvest and post-harvest activities. Energy requirements were based on: 4550 MJ/kg a.i. crop protection agents, 41.1 MJ/kg N, 18.3 MJ/kg P, 5.6 MJ/kg K and 3.7 MJ/kg S (derived from Williams et al. 2006).

Brookes and Barfoot (2009) estimated a cumulative reduction of fuel use due to zero-till to be 220.1 Mliter since 1996 in Canada. These calculations did not consider the indirect energy consumption required for the manufacture of added herbicides, however similar to environmental costs our analysis showed that energy use for manufacture of crop protection agents was much less than that for tillage operations (Figure 4.6). In calculations of the energy balance for Canadian GM OSR cultivation, Smith et al. (2007) did not find much difference with those of Mortimer et al. (2003) for the UK OSR with conventional cultivation. However, Venturi and Venturi (2003) found considerably larger energy inputs in field studies on conventional OSR in Italy.

4.3.4 Sensitivity Analysis

In order to further examine the extent to which various components influenced TFP, a sensitivity analysis was carried out. In this analysis, TFP (including environmental costs) was calculated for a range of values or costs for individual components (representing 50% lower to 50% higher than base values used). The purpose of this section was to provide insight into the effects of changes in cost of individual components that may arise from changes in economic conditions (Figure 4.7).

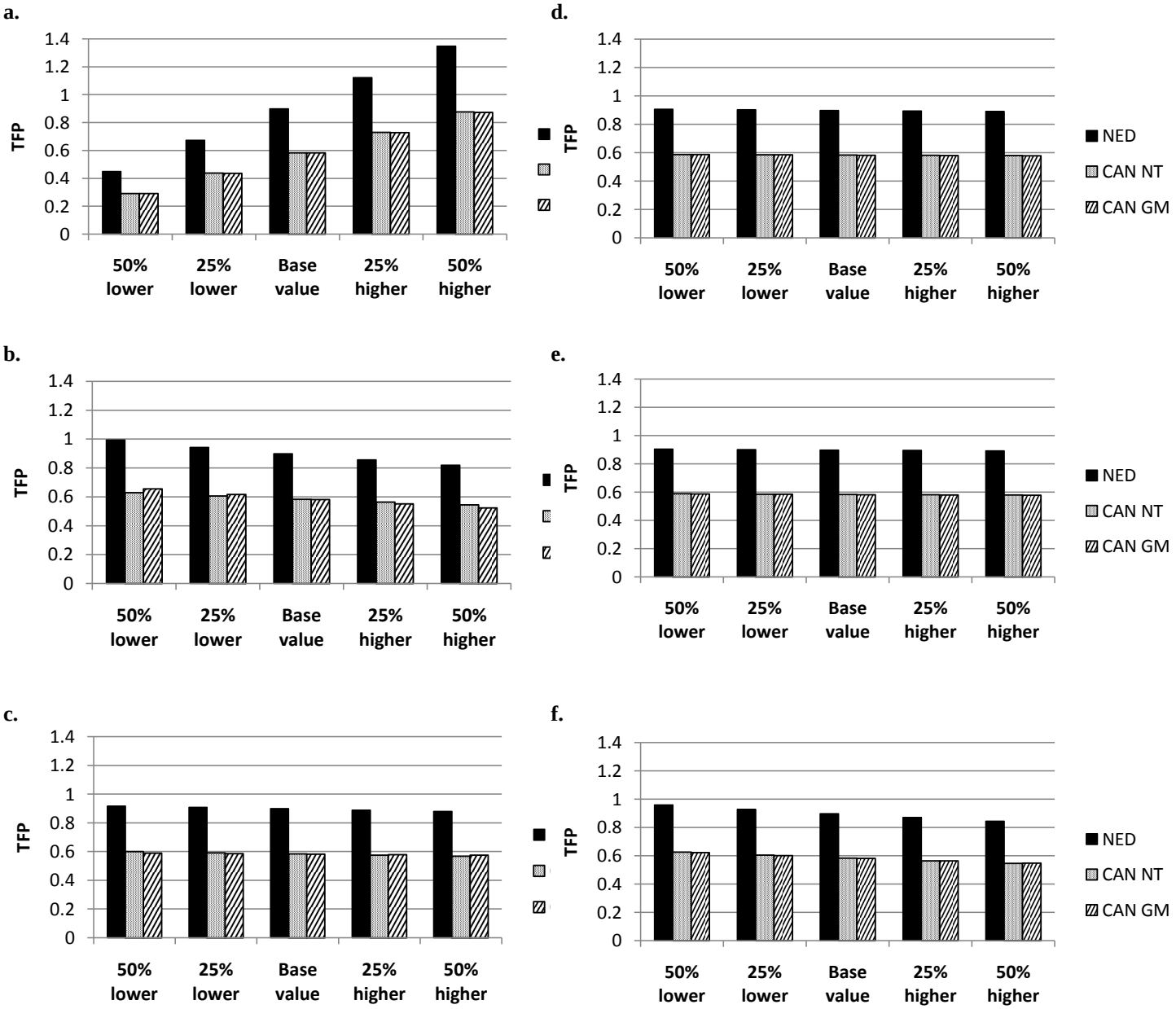


Figure 4.7. Sensitivity of oilseed rape systems in the Netherlands (NED), and conventional (CAN NT) and glyphosate tolerant systems in Canada (CAN GM) for a range of values and costs for individual components of total factor productivity (TFP). Values/costs ranged from 50% lower than base values used in this study to 50% higher than base values. Individual components shown include on farm costs (a-c) **a.** return per tonne of produce, **b.** cost of crop protection agents, **c.** cost of diesel; and costs to the environment (d-f) **d.** cost of crop protection agents to the environment, **e.** cost of GHGs to the environment, and **f.** value of ecosystem services.

Not surprisingly, as revenue from produce sales was the only form of income in this analysis, revenue per tonne of produce had a dramatic effect on TFP values. For instance, when return on produce was 50% higher than base values, the TFP index also increased by 50% in all systems. Cost of crop protection agents had a lesser but notable effect on TFP. In the Netherlands a 50% increase in cost of biocides resulted in a 9% decrease in TFP. Conversely, changes in diesel costs had minimal influence on TFP. Costs to the environment included in the sensitivity analysis had virtually no effect on TFP, since costs to the environment comprised a relatively small proportion of total costs for all situations. Therefore, although amounts assigned to environmental costs were

associated with a considerable amount of uncertainty, ultimately specific values of these costs had little effect on TFP of a system (Figure 4.7d-f).

4.4 Discussion

The majority of on farm and environmental costs (obtained from Glendining and based on data for the UK), were keep constant between locations for practical reasons as well as to make interpretation of results easier. Typical costs of OSR cultivation for Canada would certainly increase accuracy of the analysis; however additional data is not expected to change results appreciably as retail cost of various farm inputs do not likely differ substantially between developed countries. In addition, Canadian farms were not assigned lower general overhead costs, such as those often associated with larger farms. These farms may also have higher costs of materials due to transportation costs.

Determination of financial value of environmental resources is difficult and often associated with considerable uncertainty. Due to similar climatic, ecological conditions, etc. estimates of environmental processes and costs of environmental impacts based on studies in the UK may be a better representation of those in the Netherlands than in Canada. For nutrient loss for example, freshwater systems in the Netherlands are generally smaller and contain relatively large amounts of nutrients and as a result are potentially more susceptible to additional eutrophication than systems in western Canada. In terms of ecosystem services, generally the value of land increases when it becomes scarcer. In the Netherlands, the area of natural land is less than in the Prairies, and consequently this land will be more valuable. On the other hand, GHG emissions have the same cost in both locations as their environmental impacts are distributed over the globe. Changes in per unit costs GHGs or other environmental resources had a limited effect on TFP (Figure 4.7e). Improvements in methodology used to estimate quantity of GHGs generated from OSR production, for example, have a greater potential to affect whole system sustainability, however underlying environmental processes are often complex and difficult to assess.

Potential benefits to the environment provided by zero-tillage were considerable since GHG emissions had the largest contributions to environmental costs of OSR cultivation. However, these benefits only apply if farmers adopt zero-tillage with GM OSR cultivars. Although zero or reduced tillage has often been associated with GM cultivation, only 37% of glyphosate tolerant OSR in the Prairies was cultivated using zero-tillage practices in 2001-2003 (Prairie Weed Management Survey 2001-2003). Crop protection agents had a small contribution to total environmental costs (less than 10%). This is interesting because these products receive a relatively large amount of attention in scientific literature and the media in relation to GM crops as opposed to land use and GHGs. Although the most recent data available for use of crop protection agents in Canada was from 2001-2003 and this analysis assumed the same environmental impact (per kilogram of a.i.) of all biocides (see Chapter 2), changes to TFP value from these simplifications would be minor due to the relatively small contribution of biocides to total costs.

TFP indices provided a unique approach to assess the effect of changing agronomic practices on agro-ecological sustainability, in this case, adoption of GM OSR. TFP values for OSR production

in the Netherlands (although similar to those found by Glendining) barely approached 1 and were low relative to those determined by Glendining for other crops (1.09 for wheat and 1.19 for potatoes (including environmental costs)). This supports suggestions that the major benefit of OSR is its use as a break crop following cereals. Although it would be difficult to attribute a financial value to suppression of weeds, pests and diseases associated with cereals, determination of TFP values for crop rotations or even for whole farm systems (ie. including livestock, etc.) would provide a more holistic view of sustainability in OSR cultivation. For the Canadian Prairies it may also be relevant to assign a value to increased freedom in crop rotations provided by GM OSR, as TFP values did not reflect the rapid adoption of GM OSR.

4.5 Conclusions

In accordance with the definition of sustainability, it is necessary to calculate TFP over a number of years. Although this was not done here, some initial conclusions can still be drawn.

- Using the TFP approach, OSR production in the Netherlands was more sustainable than that in Canada. This difference was mainly due to much higher yields indicating a higher use efficiency of inputs in the Netherlands.
- Within Canadian systems, GM and conventional OSR had similar levels of agro-ecological sustainability, although costs to the environment were slightly lower for GM, zero-tillage systems.
- Tillage practices have a larger effect on holistic agro-ecological sustainability than use of crop protection agents for the cases considered.
- Although differences between corresponding indices were small, minor differences have a large effect over several years for farmer livelihood and the environment emphasizing the importance of data with high reliability and precision.

4.6 References

ABC. 2005. The Agricultural Budgeting and Costing Book No. 60. Agro Business Consultants Ltd, Melton Mowbray, UK.

Atkinson G, D Baldock, C Bowyer, J Newcombe, E Ozdemiroglu, D Pearce and A Provins. 2004. Framework for Environmental Accounts for Agriculture. Defra. pp. 105.

Beckie HJ, KN Harker, LM Hall, SI Warwick, A Legere, PH Sikkema, GW Clayton, AG Thomas, JY Leeson, G Seguin-Swartz and MJ Simard. 2006. A decade of herbicide-resistant crops in Canada. Canadian Journal of Plant Science. 86:1243-1264.

Costanza R, R D'Arge, R de Groot, S Farber, M Grasso, B Hannon, K Limburg, A Naeem, RV O'Neill, J Paruelo, RG Raskin, P Sutton and M van den Belt. 1997. The value of the world's ecosystem services and natural capital. Nature. 387:253-260.

Eyre N, Downing T, Hoekstra R, Rennings K and R Tol. 1997. Global warming damages: final report of the external global warming sub-task. DG Environment, European Commission, Brussels.

Follet RF. 2001. Soil management concepts and carbon sequestration zin cropland soils. Soil and Tillage Research. 61:77-92.

Glendining MJ, AG Dailey, AG Williams, FK van Evert, KWT Goulding and AP Whitmore. 2009. Is it possible to increase the sustainability of arable and ruminant agriculture by reducing inputs? Agricultural Systems. 99:117-125.

KWIN. 2009. Praktijkonderzoek Plant and Omgeving B.V. (PPO) publication 383: *Akkerbouw en Vollegrondsgroenteteelt 2009 Kwantitatieve Informatie* (KWIN).

Leeson JY, AG Thomas, HJ Beckie, CA Brenzil, LM Hall, T Andrews, KR Brown and RC van Acker. 2006. Herbicide-use trends in prairie canola production systems. Proc. 2006 Soils and Crops Workshop, University of Saskatchewan, Saskatoon, Saskatchewan, Canada. pp. 7.

Mauro IJ and SM McLachlan. 2008. Farmer knowledge and risk analysis: postrelease evaluation of herbicide-Tolerant canola in western Canada. Risk Analysis. 28(2):463-476.
Marvier M and RC van Acker. Can crop transgenes be kept on a leash? 2005. Frontiers in Ecology and the Environment. 3(2):99-106.

Nix J. 2005. Farm Management Pocketbook, 35th ed. Imperial College, Wye Campus.

Pretty JN, C Brett, D Gee, RE Hine, CF Mason, JIL Morison, H Raven, D Rayment and G van der Bijl. 2000. An assessment of the total external costs of UK agriculture. Agricultural Systems. 65:113-136.

Pretty JN, AS Ball, T Lang and JIL Morison. 2005. Farm costs and food miles: An assessment of the full cost of the UK weekly food basket. Food Policy. 30:1-20.

Pretty JN, CF Mason, DB Nedwell, RE Hine, S Leaf and R Dils. 2003. Environmental costs of freshwater eutrophication in England and Wales. Environmental Science and Technology. 37:201-208.

Siche JR, F Agostinho, E Ortega and A Romeiro. 2008. Sustainability of nations by indices: Comparative study between environmental sustainability index, ecological footprint and the emergy performance indices. Ecological Economics. 66:628-637.

Statistics Canada. 2002. Census of Agriculture 2001. Table 7 – tillage practices used to prepare land for seeding, by province, census agricultural region and census division [CD-ROM]. Stat. Reference Cent., Stat. Canada., Ottawa, ON.

Statistics Canada. Cereals and Oilseeds Review - December 2009. Agriculture Department. Published February 2010. Catalogue no. 22-007-X. vol. 32(12) ISSN 1492-4048.

Sweet JB and PJW Lutman. 2006. A commentary on the BRIGHT programme on herbicide tolerant crops and the implications of the BRIGHT and Farm Scale Evaluation programmes for the development of herbicide tolerant crops

in Europe. Outlooks on Pest Management. 17:249-254.

ten Berge HFM, JCM Withagen, FJ de Ruiter, MJW Jansen and HG van der Meer. 2000. Nitrogen responses in grass and selected field crops. Quad-Mod Parameterisation and Extensions for STONE-Application. Report 24 Plant Research International (42pp plus appendices).

Venturi P and G Venturi. 2003. Analysis of energy comparison for crops in European agricultural systems. Biomass and Bioenergy. 25:235-255.

Williams AG, E Audsley and DL Sandars. 2006. Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Main Report. Defra Research Project IS0205. Cranfield University and Defra, Bedford. Available on: www.agrilca.org, and www.defra.gov.uk.

Zentner RP, SA Brandt, KJ Kirkland, CA Campbell and GJ Sonntag. 1992. Economics of rotation and tillage systems for the Dark Brown soil zone of the Canadian Prairies. Soil & Tillage Research. 24:271-284.

5.0 Coexistence in Oilseed Rape

5.1 Introduction

Although the EU OSR market remains mostly self-sustaining with France, Germany and Poland being large OSR producers; imports from North America are likely to increase in future. Currently, 62% of Europe's rapeseed oil is destined to become biofuel, with interest in biofuels continuing to grow. Increased imports of GM OSR require clear coexistence regulations for Europe. Recognizing this, in 2002 the European Commission introduced the concept of coexistence which, through the establishment of science-based technical measures, aims to allow all markets to operate freely while reducing policy conflicts on GMOs. Coexistence was defined as "the ability of farmers to make a practical choice between conventional, organic, and GM crop productions." The concept remains highly contested and the technical measures difficult to apply due to the large variety of issues it encompasses:

- technical measures for ensuring coexistence (in field, (pollen-mediated and seed mediated gene flow), throughout the production chains (transport, processing, etc.))
- economics, legal and liability analysis
- socio-economics
- ethical concerns.

"Transgene escape" refers to movement of the inserted gene to either 1) individuals that were not transformed directly with the gene or more often to 2) descendants of the transformed individuals. Widely publicized incidents of transgene escape in OSR across western Canada have made coexistence a major public concern related to GM crops.

5.1.1 Objectives

Interspecific and intraspecific transgene movement in OSR have been well documented in the literature (Hall et al. 2000, Warwick et al. 2004, Wilkinson et al. 2003). This chapter instead focuses on practical aspects of coexistence management in Canada.

Chapter 5 of this report aims to:

- Provide an overview of current coexistence management within oilseed rape (OSR) production systems in western Canada
- Draw conclusions related to consequences of the Canadian situation for coexistence in the EU

5.2 Regulation of GM Crops

5.2.1 Canada

The Canadian government does not have regulation specific to GM crops because it regulates on the basis of the product as opposed to the process-based definition of GM varieties (used in Europe). This system is based on the principle of substantial equivalence, where GM crops are deemed to be substantially equivalent to non-GM crops with respect to regulatory requirements (CFIA 2004). GM crops and other novel plants are considered plants with novel traits (PNTs) and

are therefore regulated under the Plant Protection Act (PPA) enforced by the Canadian Food Inspection Agency (CFIA). Imidazolinone tolerant OSR is an example of a variety regulated as a PNT; subject to the same regulation as that for a GM variety in Canada.

Specifically regarding the GM issue, government action has involved consultation but few concrete regulations under the PPA (Van Acker 2007). Even following the case of Monsanto versus Percy Schmeiser, settled at the Canadian Supreme court level in May 2004, there was no governmental response in terms of new regulations or laws concerning GM crops.

The term adventitious presence (AP) is used to define "the unintended, technically unavoidable presence of genetically engineered material in an agri-food commodity" (CFIA 2005). Currently, Canada has no established thresholds for AP of transgenic material (seeds that contain HT genes, singly or stacked). AP technically also includes the reverse situation, where in HT OSR non-HT seed or another HT type would be considered AP (CSGA 2005). Since glyphosate is widely used as a broad-spectrum spring treatment to "burn-off" weeds, volunteers, etc. prior to seeding, glyphosate tolerant AP is especially problematic. Low level AP (5% or less) of conventional, glufosinate or resistant, or imidazolinone tolerant seed in glyphosate tolerant seed is of minimal agronomic importance because neither glufosinate nor acetolactate synthase inhibitors (such as imidazolinone) are normally used in spring burn-off treatments. Therefore, AP of the glyphosate tolerance trait in conventional OSR seedlots has greater agronomic implications, especially for its use as a spring burn-off treatment, than either glufosinate or imidazolinone tolerance traits (Friesen et al. 2003).

5.2.2 European Union

In the EU, GM crops fall under Directive 2001/18/EC which uses the precautionary principle to regulate deliberate release of GM organisms to the environment. GM crops must first be approved by the European Food Safety Authority (EFSA) at the EU level, and then member states grant approvals individually. With the exception of 2009, area of GM cultivation in the EU rose to over 100,000 hectares, although is mainly still limited to Bt maize (James 2008). The decrease from 2008 to 2009 was partially attributable to Germany's ban on Bt maize (MON810), which has also been banned in France since. In these cases, uncertainty under the precautionary principle was invoked to ban cultivation.

HT OSR is not grown commercially in the EU, with the exception of imidazolinone tolerant OSR. Under the definition of GM in EU regulations this product would ordinarily be considered a GM crop, but was exempted from regulation since it was developed using mutagenesis, which has a long history of safe use. As a result, in practice imidazolinone tolerant OSR is regulated as a conventional variety in Europe, and as a GM product in Canada. Therefore, paradoxically comparing conventional and GM, as in Chapter 2, differs between jurisdictions.

Regulation 1829/2003 on GM food and feed, which entered into force in April 2004, provides the legal basis for coexistence in the EU (EC 2003). According to Article 43 of the GM food and feed Regulation, member states are empowered to take appropriate measures to avoid the unintentional presence of GM material in other products. Hence, farmers should maintain their ability to make a

practical choice among conventional, organic and GM crops without excluding any agricultural options (Demont and Devos 2008). Since then the European Commission has issued non-binding guidelines on coexistence, to be developed and implemented by the member states. In the majority of states only draft measures have been issued but Germany, Denmark, Portugal, and six of the Austrian Länder have adopted coexistence guidelines into their legislation. Of the few existing coexistence regulations, most remain limited to (*Bt)* maize and to date no regulations exist for OSR.

5.3 Situation in Western Canada

Five years after the introduction of commercial production of GM OSR in western Canada, farmers began to complain about the appearance of volunteer glyphosate HT OSR in their fields, even when they had not intentionally sown these varieties the previous year (Friesen et al. 2003). Many of these farmers suspected that their certified conventional seed had AP of glyphosate-tolerant OSR. In addition, simultaneous cultivation of the various HT systems has resulted in hybridization and appearance of volunteer OSR plants with multiple HT traits (Hall et al. 2000).

Organic OSR cultivation is extremely minimal. Although this has occasionally been attributed to introduction of GM technology in the media, there has never been a large demand for organic rapeseed oil. Due to this lack of a market, organic farmers generally do not grow OSR because it is not profitable (Beckie et al. 2006). At its peak height in 1997-1999, organic OSR occupied 0.09% of total OSR area, and by 2003 this area was down to 0.04% (2000 ha) and has likely fallen since (Beckie et al. 2006). With no threshold levels for adventitious GM presence in Canada, economic loss in organic OSR cultivation was estimated to be $1-2 million between 1995 and 2000 (Brookes and Barfoot 2004). While this is a small cost compared to several billion dollars generated from OSR production of all types, these costs are borne by a small group of non-adopters of GM technology.

5.3.1 Technology Use Agreements (TUAs)

When farmers buy seed containing patented technology including RoundUp Ready OSR from Monsanto, they have to sign an annual contract referred to as a Technology Use Agreement (TUA) (or Canola Use Agreement (CUA) in the United States). The contract specifies the number of hectares a grower plans to grow, restricts farmers from saving seed annually and reserves the right to inspect a farmer's land for compliance. It also prohibits seed from being provided to third parties for any reason, including research and testing (Friesen et al. 2003). In the event of non-compliance, these TUAs may become the basis for lawsuits against farmers, as in the case of Schmeiser. Recently Monsanto also introduced a Technology Stewardship Agreement (TSA) for maize and soybean growers using Roundup Ready technology. OSR remains the only crop with a TUA.

5.3.2 Existing Segregation System in Canada

Various sources can lead to AP of GM material in non-GM products. Such sources include: the use of impure seed; cross-fertilization due to pollen flow between neighbouring fields; the occurrence of volunteer plants originating from seeds and/or vegetative plant parts from previous

GM crops; mixing in machinery during sowing, harvest and/or post-harvest operations; and, to a lesser extent, cross-fertilization from certain sexually compatible wild relatives and feral plants (Demont and Devos 2008). The many routes by which transgenes can disperse in OSR, make it difficult to develop measures enabling coexistence between GM and non-GM cultivations (Van de Wiel and Lotz 2006).

5.3.2.1 Seed Purity

The issue of foremost importance in coexistence management is seed purity. This is fundamental, because efforts further along the production chain are useless if significant levels of AP already exist. The issue of AP in seed falls under the *Seeds Act* in Canadian regulations, and is one of varietal purity and quality standards, as AP in seed (GM in non-GM seed or GM seed with a different trait) is treated no differently than the presence of other off-types; for example tall plants in a dwarf variety.

- The Association of Official Seed Certifying Agencies allows 0.25% maximum for the presence of off-types in a certified OSR seedlot (Downey and Beckie 2002).
- For breeders' seed, the tolerance level for off-types is 0.05%.
- It is widely agreed upon that it is impossible to guarantee that seed from OSR (as well as maize, soybeans, or cotton) are absolutely free of GM seeds.
- The International Seed Federation has demonstrated that the costs of ensuring genetic purity rise exponentially as threshold levels decline below 1%, to the point where costs are prohibitive at thresholds below 0.5-0.3% (ISF 2001).

Canada's certified (or pedigreed) seed production system uses an identity preservation program which can be considered relatively stringent with mandatory isolation distances, crop rotation restrictions, and inspections (CSGA 2005). For production of certified spring *Brassica napus* seed, crops cannot be planted on land which has produced *Brassica napus*, *Brassica rapa*, *Brassica juncea*, or *Raphanus sativus* during the preceding 3 years. A minimum isolation distance of 800 metres is also required between the crop for certified seed production and any of the previously mentioned crops. Within the crop, strict limits are in place for number of off-type or individuals of other varieties in addition to weeds and plants of the previously mentioned species (CSGA 2005). Adventious presence for pedigreed OSR seed can occur the same ways as in commercial OSR crops: via pollen-mediated gene flow or whole seed through persistent seed banks. Glyphosate and glufosinate tolerance are single gene, dominant traits, with the phenotype of the hemizygotes equivalent to the homozygotes. Thus in practice, both individuals resulting from persistent seed or pollen-mediated gene flow will tolerant to herbicide in the first generation (Hall et al. 2000).

Downey and Beckie (2002) investigated the purity of pedigreed OSR seedlots with respect to GM HT traits. In 70 certified OSR seedlots they found 18 of the 70 seedlot samples failed the 99.75% cultivar purity guideline. Prompted by complaints from farmers of glyphosate tolerant OSR volunteers occurring unexpectedly in fields at densities and patterns greater than those generally from pollen-mediated gene flow from neighboring fields, Friesen et al. (2003) found a higher failure rate with 14 of 27 seedlots exceeding the tolerance threshold. Friesen et al. (2003) noted that Downey and Beckie (2002) collected samples directly from pedigreed seedlots, before seed

treatment and packaging of the seed for commercial sale, while their samples were taken following this additional handling of seed and may better reflect what farmers actually plant in their fields. Most importantly, since both studies do not represent typical commercial production of OSR directly for processing or export, but certified seed for sale to farmers, these seed crops are grown with strict legal guidelines (CSGA 2002). These studies indicate that current regulations fail to meet required seed purity levels. Isolation distances enforced should limit pollen-mediated gene flow, since much smaller isolation distances of 100 m are generally sufficient to remain below an admixture level of 0.1% (Van de Wiel & Lots 2006). It is more likely that AP in certified seedlots exceeding cultivar purity guidelines was from soil seed banks as 3 years between crossable crop species is rather low compared to publications on seed bank persistence for OSR. Seeds may enter into secondary dormancy and survive in seed banks for over 10 years (Van de Wiel & Lots 2006). Other possible sources included: mixing during harvest or handling, or contamination occurring in earlier generations of pedigreed seed production (i.e. breeders' seed) (Downey and Beckie 2002).

These studies suggest that the current segregation system fails to meet genetic purity standards for pedigreed OSR seed in western Canada according to certification requirements. If this is in fact the case, farmers not wanting to grow GM OSR may not be satisfied with seed purchased as non-GM varieties. This would also be true of non-pedigreed (common) seed. If this is the case then farm-saved seed or speciality suppliers may be the only option for farmers wanting to start with seed meeting cultivar purity guidelines (Van Acker 2007). Downey and Beckie (2002) argued that even if the 0.25% contamination guideline for certified seed is not exceeded, unexpected presence of herbicide resistance traits in volunteer OSR is still likely to occur at frequencies that are of concern to farmers the following year. Assuming a 0.25% presence level of a herbicide tolerance trait, a typical seeding rate of 5.5 kg/ha and thousand-seed weight of 4.0 g per thousand seeds, they estimated 1 herbicide tolerant volunteer plant every 1.3 m^2. This density would be considered a weed problem if the farmer sprays with glyphosate alone, however if the following crop is a cereal yield losses are not likely to occur because cereals are relatively competitive. If the crop is less competitive than cereals such as flax, lentil, or field bean, yield losses are likely to occur (Downey and Beckie 2002).

5.3.2.2 Separation throughout Production Chains

Admixture of seed can occur at many points within a given product handling system. Farming equipment is a common vector for the dispersal of weed seeds as well as crop seeds from field to field. Although cleaning farm equipment, as well as storage, transport and grain handling facilities are simple steps, it can be difficult to clean some pieces of equipment, such as commercial combine harvesters. The experience of Canadian producers suggests that even the most meticulous cleaning of equipment between fields and crop types cannot guarantee prevention of trace levels of co-mingling (AAFC 2004).

OSR is subjected to grading that segregates the seed into parcels with similar quality according to the *Canada Grain Act* (DeClercq and Daun 2005). Seed is sampled at several points along the handling system and these samples are analyzed by the Canadian Grain Commission for quality criteria including: oil content, chlorophyll content, glucosinolate and erucic acid levels, saturated fatty acids and dockage (foreign material often weed seeds). Segregation by seed grade is applied

throughout commodity production and handling systems, while segregation of GM from conventional seed has not been attempted on the same scale. In practice, quality parameters are routinely tested and AP of GM seeds is not. A Canadian Grain Commission study of the quality of GM and conventional OSR seed harvested from 1996-2001 using these grading samples found quality of GM cultivars to be equal to or better than conventional cultivars for the individual quality parameters mentioned above (Daun 2004). Superior weed control (as mentioned in Chapter 2 and 3) resulted in significantly reduced weed seed contamination in GM varieties, as well as lower levels of glucosinolates, possibly due to a decreased presence of cruciferous weeds.

AP is harder to avoid in commodities that pass through bulk handling facilities used for GM crop varieties (Van Acker et al. 2007). Whether for export or crushing for domestic consumption, oilseed generally enters large facilities where high-throughput pieces of equipment are not only difficult to clean, but their continuous use in elevators and processing facilities makes cleaning between loads impractical. Currently, handling throughout the OSR production chain is the same for GM and non-GM produce and is comparable to handling of malt barley and feed barley, or feed wheat and high protein red spring wheat, for example. Equipment used in storage, transporting and processing is cleaned briefly between products, and although all generally agree a policy of zero tolerance for AP is not possible (technically unattainable or economically not affordable), no thresholds have been established.

Many domestic and international customers of Canadian grains, oilseeds and special crops have made certification of the absence of GM content a condition of doing business. As a result, in 2004 suppliers and the Canadian Grain Commission implemented a voluntary certification program for the absence of GM material. This program is called the Canadian Identity Preservation Recognition System (CIPRS) and provides audits and certification of industry protocols. To meet the program standard, a company must document procedures for keeping specialty products segregated and records to demonstrate that these procedures have been followed. To date, only a small portion of the entire grain handling industry participates in this program and the majority of these are involved in the export of non-GM soybeans for human consumption in Europe (L. Anderson, *personal communication*).

5.3.3 Compliance to Regulations: Bt Maize in Canada

Although there are no legally binding regulations for coexistence in Canada, many stewardship practices have been recommended. For OSR, an isolation distance of 800 metres between GM and non-GM growers has been suggested, which is a common field dimension in western Canada (Beckie et al. 2006). However as is commonly stated in discussions, these types of technical measures are difficult to apply and enforce in practice. In terms of compliance to legislation, the situation can be compared to enforcement of refuge non-Bt maize in Bt maize fields. In the "high dose/refuge strategy" adopted by the North American maize industry, producers are required by law to maintain at least 20% refuge maize within 400 metres of Bt maize fields (Sears and Schaafsma 1998). The company selling the transgenic seed is required to inform producers of this requirement by means of a TUA. Producers are also obligated to scout their fields twice per year for corn borer damage. If growers do not follow the refuge requirements, the seed company should restrict or deny sale of trangenic seed to the grower.

Since 2001, grower compliance to these requirements has been monitored by the Canadian Food Inspection Agency (CFIA) through a telephone survey every two years. Although in general, results have shown that grower compliance is high (90%), the latest survey in 2007 indicated a sharp decrease in compliance to 70% (Dunlop 2009). As a result, the CFIA has begun performing on-farm field inspections in years when the survey is not conducted to encourage increased compliance. For this example, compliance issues may be solved shortly as "refuge in the bag" products, where non-Bt seeds are pre-mixed with Bt sowing seeds, are well into the regulatory process in Canada and the United States. At the same time, this experience shows general willingness of individual farmers to adhere to regulations which are not easily enforceable.

5.4 Loss of Market Access

The most important risk identified by Canadian farmers related to growing GM OSR was not increased problems with HT volunteers, but loss of market access (Mauro and McLachlan 2008). In the past, several incidence related to GM have had detrimental effects on Canadian exports. Until recently, imports of OSR from North America were banned due to fear of the presence of the unapproved GM OSR variety, T45. Strictly, this was not a case of failure of coexistence management, but one of asynchronous approval of GM varieties across nations for health and environmental safety regulation. In theory, the reverse situation could have occurred as Canada also has a zero tolerance policy for GM varieties that are unapproved. On the other hand, failure to meet seed purity guidelines due to AP levels in excess of guidelines, as described above, is strictly an issue of coexistence. Particularly in maize seed, the Canadian Seed Trade Association has identified AP in pedigreed seed as being a contributing factor in the decline in global seed trade (AAFC 2004). Whatever the cause, asynchronous approvals of GM products or failure of segregation systems to meet guidelines, the result is loss of global markets and domestic economic damage. The threat of market harm was also highlighted by the controversy surrounding Monsanto's GM wheat in 2006, with over 80% of world grain buyers indicating that they would not purchase this technology if it were grown and marketed in North America (Mauro and McLachlan 2008).

5.5 Conclusions

- Large scale segregation of GM from conventional OSR produce has not been attempted in Canada and without mandatory testing for GM material throughout commodity production and handling systems, handlers have little or no motivation to segregate GM crops effectively (Van Acker et al. 2007).
- Segregation is attempted for small scale products such as seed and specialty products of high value including organic OSR production.
- The problematic Canadian experience in meeting purity guidelines of 0.25% for certified seed indicates the complexity and difficulty in coexistence management for OSR.
- Many of these problems are derived from the persistent nature of OSR seed in seed banks and from large seed losses in harvesting due to small seed size.

If current laws prohibiting cultivation of GM OSR in Europe are upheld, logically problems similar to those experienced in Canada can be avoided. However, with imports of GM OSR from North America likely to increase in future and continued GM soy imports from South America, there is still a need for large scale segregation systems in commodity transport, processing and handling systems unlike any that have been attempted globally to date. From an ethical perspective, maintenance of "GM-free" products is a freedom of choice issue for growers and consumers, which should be upheld by law in most jurisdictions. Although socio-economic and ethical issues cannot be addressed in this report, they are certainly important for coexistence management.

In contrast from a purely economic perspective, maintenance of the various OSR production systems may not be critical. Coexistence, particularly for OSR production, has been an issue in Canada for over 10 years. The lack of organic and conventional OSR production in western Canada shows there is little consumer demand for these products and the recent approval of import of GM OSR to the EU also emphasizes this point. It appears that for consumers, the presence of GM material in processed foods is not nearly as large an issue as cultivation of GM crops. This has been reflected in the inaction of the Canadian government to develop and implement coexistence regulations due to a perceived lack of benefit, likely associated with economic costs of doing so. It would be interesting to compare the cost of numerous lawsuits over time to the estimated cost of realistic segregation regulations.

5.6 References

Agriculture and Agri-Food Canada (AAFC) 2004. Industry and government perspectives on AP of products of genetic engineering in seeds, grains, oilseeds and special crops: a discussion paper. Prepared by InterSect Alliance Inc. on behalf of: Agriculture and Agri-Food Canada, Canadian Food Inspection Agency, Canadian Grain Commission.

Canadian Food Inspection Agency (CFIA). 2004. Directive 94-08: Assessment criteria for determining environmental safety of plants with novel traits (revised 2004). Available online: www.inspection.gc.ca/english/plaveg/bio/dir/dir9408e.shtml.

Canadian Food Inspection Agency (CFIA). 2005. Food safety enhancement program HACCP curriculum guidelines. Available online: www.inspection.gc.ca/english/fssa/polstrat/haccp/manue/tablee.shtml.

Canadian Seed Growers' Association (CSGA). 2005. Circular 6: Canadian regulations and procedures for pedigreed seed crop production certified production of hybrid canola and rapeseed. Canadian Seed Growers' Association, Ottawa, ON.

Daun JK. 2004. Quality of genetically modified (GM) and conventional varieties of canola (spring oilseed rape) grown in western Canada, 1996–2001. Journal of Agricultural Science. 142:273-280.

Demont M and Y Devos. 2008. Regulating coexistence of GM and non-GM crops without jeopardizing economic incentives. Trends in Biotechnology. 26(7):353-358.

DeClercq DR and JK Daun. 2005. Grain Research Laboratory Canadian Grain Commission. Winnipeg, MB, Canada. Presented as a poster at the GCIRC Technical Meeting, Winnipeg MB, June 26-28, 2005.
Paper number 891 from the Canadian Grain Commission, Grain Research Laboratory.

Dunlop G. AgData (Canada) Ltd. 2009. Bt Corn IRM Compliance in Canada. Canadian Corn Pest Coalition Report. Available online: http://www.cornpest.ca/index.cfm/resistance-management/are-canadian-growers-following-irm/.

European Council (EC) Regulation 1829/2003 of the European Parliament and of the Council of 22 September 2003 on genetically modified food and feed. 2003. Official Journal of the European Communities L268, 1-23. Available online: http://eur-lex.europa.eu/LexUriServ/site/en/oj/2003/l_268/l_26820031018en00010023.pdf.

Friesen LF, AG Nelson and RC Van Acker. 2003. Evidence of contamination of pedigreed canola (*Brassica napus*) seedlots in western Canada with genetically engineered herbicide resistance traits. Agronomy Journal. 95:1342-1347.

Hall L, K Topinka, J Huffman, L Davis and A Good. 2000. Pollen flow between herbicide-resistant *Brassica napus* is the cause of multiple-resistant *B. napus* volunteers. Weed Science. 48:688-694.

International Seed Federation (ISF). 2001. Motion on adventitious presence of GM material in non-GM seeds. ISF position paper. Available online:
http://www.worldseed.org/cms/medias/file/PositionPapers/OnSpecificTechnicalSubjects/Coexistence_of_Genetically_Modified_Conventional_and_Organic_Crop_Production_20040526_(En).pdf.

Lutman PJW, K Berry, MJ May, GT Champion, JH Clarke and SK Cook. 2007. Rothamsted Research, Rothamsted Research – Broom's Barn, and ADAS Boxworth. Agronomic and environmental implications of the establishment of GM herbicide tolerant problem weeds (project CPEC 45).

Mauro IJ and SM McLachlan. 2008. Farmer knowledge and risk analysis: postrelease evaluation of herbicide-tolerant canola in western Canada. Risk Analysis. 28(2):463-476.

Monsanto US ag products, Genuity™ Roundup Ready® OSR. Available online:
http://www.monsanto.com/monsanto/ag_products/input_traits/products/roundup_ready_OSR.asp.

Sears M and A Schaafsma. 1998. Responsible Deployment of *Bt* Corn Technology in Ontario. *Bt* Corn Coaltion.

Warwick SI, A Legere, MJ Simard and T James. 2008. Do escaped transgenes persist in nature? The case of an herbicide resistance transgene in a weedy Brassica rapa population. Molecular Ecology. 17(5):1387-1395.

Warwick SI, MJ Simard, A Legere, HJ Beckie, L Braun, B Zhu, P Mason, G Seguin-Swartz and CN Stewart. 2004. Hybridization between transgenic *Brassica napus* L. and its wild relatives: *Brassica rapa* L., *Raphanus raphanistrum* L., *Sinapis arvensis* L., and *Erucastrum gallicum* (Willd.) OE Schulz. Theoretical and Applied Genetics. 107(3):528-539.

Wilkinson MJ, LJ Elliott, J Allainguillaume, MW Shaw, C Norris, R Welters, M Alexander, J Sweet and DC Mason. 2003. Hybridization between *Brassica napus* and *B. rapa* on a national scale in the United Kingdom. Science. 302:457-459.

Van Acker RC, N McLean and RC Martin. 2007. Development of quality assurance protocols to prevent GM-contamination of organic crops. Page 466-486. In the: Handbook of organic food safety and quality. Edited by: J Cooper, U Niggli, C Leifert. Woodhead Publishing Limited, Cambridge, UK.

Van de Wiel CCM and LAP Lotz. 2006. Outcrossing and coexistence of genetically modified with (genetically) unmodified crops: a case study of the situation in the Netherlands. NJAS Wageningen Journal of the Life Sciences. 54:17-35.

6.0 Conclusions

6.1 Crop Protection

Crop protection data from the 2001-2003 Prairie Weed Management Survey suggested that herbicide use intensity has increased with the adoption of HT OSR, however this increase has not resulted in a greater environmental impact than that in conventional OSR. Our results indicated an increase of 18.5% in herbicide use intensity and a slight decrease of 1.9% in environmental impact when all HT systems were combined. These findings are in sharp contrast to others reported in the literature. Brookes and Barfoot (2009) and Leeson et al. (2006) both estimated reductions of 12% in herbicide use intensity and corresponding reductions in environmental impact of 20% and 22%, respectively. Although data sources and methods differed between our study and particularly that of Brookes and Barfoot, the most important difference was the time period over which conclusions were drawn. The previous studies drew comparisons over 11 and 7 years after the introduction of HT varieties, a relatively long time span in terms of change in crop protection practices. For example, in the Netherlands herbicide use intensity decreased from 2.34 kg a.i./ha to 1.18 kg a.i./ha over a period of 8 years (from 2002-2009). Similarly for the years following 1995, herbicide use intensity in conventional canola alone decreased by approximately 25% in western Canada.

There are several valid reasons for conducting these comparisons over longer time frames, the most important being to limit the effect of variability in conditions between years. Furthermore, there is now relatively little area of conventional OSR cultivated on the Canadian Prairies. Therefore, it is possible that non-adopters of HT technology tend to be different than HT adopters with respect to other agronomic practices. If this is the case, then a comparison to the past may be more valid. At the same time, within year comparisons are still representative for a given season, with for example comparable weather conditions. More recent survey data from western Canada will be important to determine if findings of this study are consistent over a longer time frame.

Historically, it is common to compare the results of changes in agronomic practice to the past; and there are several valid reasons for doing so:

- To limit the effect of variability in conditions between years
- In the case of OSR in Canada, area of conventional OSR production in recent years is minimal. These few “non-adopters” of HT varieties may also differ from HT growers in other agronomic practices.

On the other hand, within year comparisons (or comparisons over short time periods) are valid representations for a given season. In this case, our results are not robust enough to conclude that the introduction of HT varieties has resulted in greater amounts of herbicide application to OSR in western Canada, however our results do show that from 2001-2003 application rates were higher in HT varieties, suggesting this may be true for other years. More recent survey data will be important to see if these findings hold true.

6.2 Crop Productivity

Similar to crop protection, OSR productivity is constantly being improved over time. With simultaneous efforts in breeding and improvements in agronomic practice, it is often difficult to determine the cause of increased productivity. This is indeed the case for the HT trait. Although far fewer studies have investigated yield than herbicide usage, some evidence exists for significantly higher yields of HT cultivars in the Prairies (Stringham et al. 2003, Harker et al. 2000). The HT trait itself does not directly increase yields, but gains of up to 10% greater than conventional OSR have been associated with the trait. Possible explanations include:

- Reduced competition due to better weed control in situations of high weed pressure (Harker et al. 2000)
- HT varieties allowed farmers to plant earlier than with conventional due to their differing herbicide regimes. Herbicides used in conventional cropping require soil-incorporation prior to sowing and as a result are not compatible with zero-tillage practices. Therefore, a lack of tillage with HT cultivars could allow farmers to sow earlier in the season.

Based on annual rate of increase in OSR yield from 1988 to 2010, our results did not support greater yields from HT varieties. As a result, rapid farmer adoption in western Canada was not due to improved productivity alone, but can be better explained by operational benefits including more flexibility in crop rotations and improved ease and efficiency of weed control (Mauro and McLachlan 2008).

Despite some evidence for higher yields using HT OSR in Canada, yields in western Europe have remained approximately twice as great. This was mainly attributed to the lower yield of spring varieties compared to winter OSR, the main type of OSR grown in western Europe. Winter OSR cannot survive the harsher winters in Canada, and consequently exclusively spring types are grown. Spring types have a shorter growing season and genotypic differences that result in lower yields. Other factors are lower inputs and occasional drought in western Canada.

6.3 Agro-ecological Sustainability via Total Factor Productivity (TFP)

The total factor productivity index proved to be a useful tool in assessing sustainability. In the analysis in Chapter 4, mainly costs from the UK were used to represent costs in the Netherlands and Canada. Thus in this case, absolute TFP values relative to 1 were not accurate representations of sustainability and relative values of the systems was more meaningful. However, if the necessary data collection from the Netherlands and Canada was carried out, absolute values could be accurate measures of sustainability. On farm costs for labour, machinery repairs, etc. could be collected relatively easily from surveys or statistics agencies. This was not done in the present analysis in the interest of time and to keep interpretation of results relatively simple. Estimates of costs of environmental impacts however are difficult to obtain; both estimates of environmental impact as well as the costs associated with these environmental impacts. It is doubtful that such estimates specific to the Netherlands and Canada exist.

Regardless, TFP indices indicated more sustainable OSR production in the Netherlands than that in the Canadian Prairies. This was mainly due to higher yields indicating higher use efficiency of inputs in the Netherlands. On the Canadian Prairies, GM and conventional OSR had similar levels

of agro-ecological sustainability, despite the higher herbicide use in GM production found in Chapter 2. Similarly, tillage practices (plough-based versus zero-tillage) were more important to overall agro-ecological sustainability than GM or non-GM varieties. In this way, GM systems are more sustainable if zero-tillage is also adopted with HT technology, however in 2002 only 37% of glyphosate tolerant OSR growers practice zero-tillage.

Ideally, TFP would be calculated over a crop rotation of several years for each of the systems analyzed to provide more robust estimates of overall sustainability. Barnett et al. (1994) performed this type of analysis for long-term experimental field trials and described how to analyze trends in TFP over time for multiple systems.

6.4 Coexistence

The Canadian experience with GM OSR emphasizes difficulties in segregation related to cultivation of this crop. However, even if cultivation of GM OSR in Europe remains prohibited, increasing imports of GM OSR from North America require large scale commodity segregation systems. Large scale segregation of this nature has not been attempted in Canada due to lack of consumer demand. Small scale segregation occurs for organic, specialty products and seed; however significant failures of these systems have been reported (Friesen et al. 2003). Thus far for OSR, economic consequences strictly due to failure of segregation systems have been minimal, although these costs tend to be borne by few stakeholders.

6.5 Future Outlook

OSR production in the Canadian Prairies continues to be overwhelmingly dominated by HT varieties. This situation is unlikely to change unless problems in one or more of the following areas become important in future.

- Continued reductions in herbicide use in conventional OSR.
- Loss of markets, particularly the EU if the general rejection of GM crops persists.
- Increasing occurrence of HT volunteers in subsequent crops.

Besides OSR, glyphosate tolerant alfalfa and sugar beet have both recently been approved in Canada for unconfined release. With these three crops grown in rotations across the Prairies, the currently extensive use of glyphosate would increase, causing even greater selection pressure and increased occurrence of glyphosate resistant weeds and volunteers. In addition, because of the dependence of conservation tillage practices on glyphosate (for pre-seeding burn off), increased abundance of resistant individuals has implications for the viability of these practices, and thereby agro-ecological sustainability for all farmers in western Canada.

For Europe, where consumer demand for “GM-free” products appears to continue, failure of segregation systems of other states will potentially cause problems for imports and international trade. In theory, this problem could be avoided if the EU were to remain mainly self-sufficient for OSR production; however current trends are towards the contrary.

Commercial release of "second generation" GM cultivars is rapidly approaching, with traits such as pharmaceuticals and drought tolerance. For OSR, these traits may include:

- Insect resistance (Bt)
- Oil composition, for industrial products for example
- Protein composition, for livestock feed

Coexistence management will become more important as new traits are developed, stressing the need for coherent coexistence guidelines in jurisdictions where none yet exist. In the few EU member states where coexistence legislation has been adopted, in future these regulations will need to include more comprehensive guidelines that cover as many routes for gene escape as possible.

6.6 References

Barnett V, S Landau and SJ Welham. 1994. Measuring sustainability. Environmental and Ecological Statistics. 1:21-36.

Friesen LF, AG Nelson and RC Van Acker. 2003. Evidence of contamination of pedigreed canola (*Brassica napus*) seedlots in western Canada with genetically engineered herbicide resistance traits. Agronomy Journal. 95:1342-1347.

Mauro IJ and SM McLachlan. 2008. Farmer knowledge and risk analysis: postrelease evaluation of herbicide-tolerant canola in western Canada. Risk Analysis. 28(2):463-476.

Appendix 2.1: Calculations for combining herbicide tolerant (HT) system data.

In order to look at herbicide use intensity and *field* EIQ as a comparison between HT and conventional (NT) OSR, first the various HT systems must be combined. When systems are combined an average weight should be used. In this case, weights were based on land area of each HT system under cultivation. An unweighted average assumes that area of each system is equal, which was certainly not true. Weights were calculated by Julia Leeson, Agriculture and Agri-Food Canada and represented the percentage of total area of OSR in the three Prairies Provinces for each system.

Calculations are shown below. Weight of each individual system was summed, multiplied by the value (herbicide use intensity or *field* EIQ) for a given system, and divided by the total of all weights. Note that these weighted averages are dependent on the area planted to each of the HT varieties, and therefore reflects one moment in time.

Herbicide use intensity

System		Average herbicide use intensity (kg ai/ha)	Weights (%)	Weighted average per system (kg ai/ha)	Weighted average across systems (kg ai/ha)	Change in herbicide use intensity (%)
Non-tolerant (conventional)	NT	0.763	7.601	5.780	0.763 (NT)	**18.492**
Glufosinate tolerant	LL	0.986	17.440	17.190	0.904 (LL, RR, CL)	
Glyphosate tolerant	RR	1.001	34.256	34.270		
Imidazolinone tolerant	CL	0.574	14.363	8.247		

Environmental impact (*field* EIQ)*

System		*field* EIQ (per hectare)	Weights (%)	Weighted average per system (*field* EIQ/ha)	Weighted average across systems (*field* EIQ/ha)	Change in herbicide use intensity (%)
Non-tolerant (conventional)	NT	15.278	7.601	116.120	15.278 (NT)	**-1.987**
Glufosinate tolerant	LL	18.013	17.440	314.141	14.974 (LL, RR, CL)	
Glyphosate tolerant	RR	15.574	34.256	533.520		
Imidazolinone tolerant	CL	9.853	14.363	141.525		

*Based on herbicides applied only.

Appendix 2.2: Toxicological and environmental behaviour data for metazachlor and metconazole for environmental impact analysis.

For the herbicide metazachlor and fungicide metconazole, EIQ values were not available from Cornell University, Integrated Pest Management Program. Relevant toxicological and environmental behaviour data of the closely related compounds metolachlor and ipconazole were checked with corresponding data for metazachlor and metconazole and used as substitutes in the EIQ equation. These data are translated into a score (either 1, 3 or 5) for use in the equation, thus similar toxicological and environmental behaviour values are entered into the equation as the same score.

Equation for the environmental impact quotient (EIQ).

$$EIQ=\{C[(DT*5)+(DT*P)]+[(C*((S+P)/2)*SY)+(L)]+[(F*R)+(D*((S+P)/2)*3)+(Z*P*3)+(B*P*5)]\}/3$$

C = chronic toxicity (1-3-5)
DT = dermal toxicity (1-3-5)
P = plant surface residue half-life (1-3-5)
S = soil half-life (1-3-5)
SY = systemicity (1-2-3)
L = leaching potential (1-2-3)
F = fish toxicity (1-2-3)
R = surface loss potential (1-3-5)
D = bird toxicity (1-3-5)
Z = bee toxicity (1-3-5)
B = beneficial arthropod toxicity (1-3-5)

Selected physiochemical and toxicological data for metazachlor (A) and metconazole (B) and their substitutes. Data from Footprint, pesticide properties database (PPDB), Agriculture & Environment Research Unit (AERU), University of Hertfordshire.

A. Metazachlor and substitute metolachlor.

General

	Metazachlor	**Metolachlor**
Pesticide Type	Herbicide	Herbicide
Chemical Group	Chloroacetamide	Chloroacetamide
Mode of Action	Ergosterol inhibitor	Selective, reduces seed germination. Inhibition of mitosis and cell division.
CAS RN	67129-08-2	51218-45-2
Chemical Formula	$C_{14}H_{16}ClN_3O$	$C_{15}H_{22}ClNO_2$
Molecular Mass (g mol^{-1})	277.75	283.8
IUPAC Name	2-chloro-*N*-(pyrazol-1-ylmethyl)acet-2',6'-xylidide	2-chloro-*N*-(6-ethyl-o-tolyl)-*N*-[(1*RS*)-2-methoxy-1-methylethyl]acetamide
Other status information	-	Potential groundwater contaminant

Environmental Fate

	Metolachlor	Value	Description	Notes
Soil degradation (days) (aerobic)	DT50 (typical):	90	Moderately persistent	
	DT50 (lab at 20oC):	15.0	Non-persistent	General literature lab studies DT50 range 8-38
	DT50 (field):	21.0	Non-persistent	Switzerland and France field studies DT50 range 11-31 Other data field studies DT50 range 6-100
GUS leaching potential index	-	3.32	High leachability	Calculated
Koc - Organic-carbon sorption constant (ml g^{-1})		200	Moderately mobile	Other sources: 120.2-309.0

	Metazachlor	Value	Description	Notes
Soil degradation (days) (aerobic)	DT50 (typical):	77	Moderately persistent	
	DT50 (lab at 20^{o}C):	15.6	Non-persistent	EU dossier lab studies DT50 range 5.8-25.3
	DT50 (field):	6.8	Non-persistent	EU dossier field studies DT50 range 2.8-21.3; Other data field studies DT50 range 26-114
GUS leaching potential index	-	3.53	High leachability	Calculated
Koc - Organic-carbon sorption constant (ml g^{-1})		134	Moderately mobile	EU dossier Kfoc range 53.8-220

Ecotoxicology

	Metazachlor	Value	Description	Notes
Mammals - Acute oral LD50 (mg kg^{-1})		> 2000	Moderate	Rat
Birds - Acute LD50 (mg kg^{-1})		2000	Moderate	*Colinus virginianus*
Fish - Acute 96 hour LC50 (mg l^{-1})		8.5	Moderate	*Oncorhynchus mykiss*
Fish - Chronic 21 day NOEC (mg l^{-1})		2.15	-	*Oncorhynchus mykiss*
Aquatic invertebrates - Acute 48 hour EC50 (mg l^{-1})		33	Moderate	*Daphnia magna*
Aquatic plants - Acute 7 day EC50, biomass (mg l^{-1})		0.0023	High	*Lemna gibba*
Honeybees - Acute 48 hour LD50 (µg bee^{-1})		72.2	Moderate	Oral
Earthworms - Acute 14 day LC50 (mg kg^{-1})		500	Moderate	*Eisenia foetida*
Other arthropod (1)	LR50 g ha^{-1}:	7.5	Harmful at 1 kg ha^{-1}	*Aphidius rhopalosiphi*
Other arthropod (2)	LR50 g ha^{-1}:	7.5	Harmful at 1 kg ha^{-1}	*Typhlodromus pyri*

	Metolachlor	Value	Description	Notes
Mammals - Acute oral LD50 (mg kg^{-1})		1200	Moderate	Rat
Birds - Acute LD50 (mg kg^{-1})		2000	Moderate	*Anas platyrhynchos*
Fish - Acute 96 hour LC50 (mg l^{-1})		3.9	Moderate	*Oncorhynchus mykiss*
Fish - Chronic 21 day NOEC (mg l^{-1})		-	-	-
Aquatic invertebrates - Acute 48 hour EC50 (mg l^{-1})		23.5	Moderate	*Daphnia magna*
Aquatic plants - Acute 7 day EC50, biomass (mg l^{-1})		0.043	Moderate	*Lemna gibba*
Honeybees - Acute 48 hour LD50 (µg bee^{-1})		110	Low	Oral
Earthworms - Acute 14 day LC50 (mg kg^{-1})		140	Moderate	
Other arthropod (1)	LR50 g ha^{-1}:	-	-	-
Other arthropod (2)	LR50 g ha^{-1}:	-	-	-

Health issues

	Metazachlor	Metolachlor
Carcinogen	no	unknown
Endocrine disrupter	-	unknown
Reproduction / development effects	-	-
Acetyl cholinesterase inhibitor	no	no
Neurotoxicant	no	no
Respiratory tract irritant	no	no
Skin irritant	yes	yes
Eye irritant	yes	yes

B. Metconazole and substitute ipconazole

General

	Metconazole	Ipconazole
Pesticide Type	Fungicide	Fungicide
Chemical Group	Triazole	Triazole
Mode of Action	Systemic, ergosterol biosysnthesis inhibitor	Systemic, broad-spectrum, inhibits sterol synthesis in fungi
CAS RN	125116-23-6	125225-28-7
Chemical Formula	C_{17} $H_{22}ClN_3O$	$C_{18}H_{24}ClN_3O$
Molecular Mass (g mol^{-1})	319.83	333.9
IUPAC Name	(1RS,5RS;1RS,5SR)-5-(4-chlorobenzyl)-2,2-dimethyl-1-(1H-1,2,4-triazol-1-ylmethyl)cyclopentanol	(1RS,2SR,5RS;1RS,2SR,5SR)-2-(4-chlorobenzyl)-5-isopropyl-1-(1H-1,2,4-triazol-1-ylmethyl)cyclopentanol
Other status information	-	-

Environmental Fate

	Metconazole	Value	Description	Notes
Soil degradation (days) (aerobic)	DT50 (typical):	84	Moderately persistent	
	DT50 (lab at 20°C):	84	Moderately persistent	EU dossier lab studies DT50 range 84-598
	DT50 (field):	265	Persistent	EU dossier field studies DT50 range 33-845; European soils field studies DT50 range 283-854
GUS leaching potential index	-	1.83	Transition state	Calculated
Koc - Organic-carbon sorption constant (ml g^{-1})		116	Slightly mobile	EU dossier Kfoc range 726-1718 on 9 soils

	Ipconazole	Value	Description	Notes
Soil degradation (days) (aerobic)	DT50 (typical):	50	Moderately persistent	
	DT50 (lab at 20oC):	-	-	
	DT50 (field):	330	Persistent	EU dossier field studies DT50 range 330-1386; Other data field studies DT50 range 45-54
GUS leaching potential index	-	0.89	Low leachability	Calculated
Koc - Organic-carbon sorption constant (ml g^{-1})		3001	Slightly mobile	Koc range 45-146

Ecotoxicology

	Metconazole	Value	Description	Notes
Mammals - Acute oral LD50 (mg kg^{-1})		595	Moderate	Rat
Birds - Acute LD50 (mg kg^{-1})		787	Moderate	*Colinus virginianus*
Fish - Acute 96 hour LC50 (mg l^{-1})		2.1	Moderate	*Oncorhynchus mykiss*
Fish - Chronic 21 day NOEC (mg l^{-1})		1.14	-	*Oncorhynchus mykiss*, 28 day
Aquatic invertebrates - Acute 48 hour EC50 (mg l^{-1})		4.2	Moderate	*Daphnia magna*
Aquatic plants - Acute 7 day EC50, biomass (mg l^{-1})		-	-	-
Honeybees - Acute 48 hour LD50 (µg bee^{-1})		85	Moderate	Oral
Earthworms - Acute 14 day LC50 (mg kg^{-1})		> 500	Moderate	*Eisenia foetida* (corr)

Other arthropod (1)	% Effect:	-45.2	Harmless	Mortality Dose: 2 x 90 g ha^{-1} *Aphidius rhopalosiphi* (adult)
Other arthropod (2)	% Effect:	3.4	Harmless	Mortality Dose: 2 x 90 g ha^{-1} *Typhlodromus pyri* (protonymph)

	Ipconazole	**Value**	**Description**	**Notes**
Mammals - Acute oral LD50 (mg kg^{-1})		888	Moderate	F3 Rat
Birds - Acute LD50 (mg kg^{-1})		962	Moderate	L3 *Colinus virginianus*
Fish - Acute 96 hour LC50 (mg l^{-1})		1.3	Moderate	L3 *Oncorhynchus mykiss*
Fish - Chronic 21 day NOEC (mg l^{-1})		-	-	-
Aquatic invertebrates - Acute 48 hour EC50 (mg l^{-1})		1.7	Moderate	L3 *Daphnia magna*
Aquatic plants - Acute 7 day EC50, biomass (mg l^{-1})		-	-	-
Honeybees - Acute 48 hour LD50 (µg bee^{-1})		-	-	-
Earthworms - Acute 14 day LC50 (mg kg^{-1})		-	-	-
Other arthropod (1)	% Effect:	-	-	-
Other arthropod (2)	% Effect:	-	-	-

Health issues

	Metconazole	**Ipconazole**
Carcinogen	no	uknown
Endocrine disrupter	-	-
Reproduction / development effects	unknown	unknown
Acetyl cholinesterase inhibitor	no	no
Neurotoxicant	no	no
Respiratory tract irritant	yes	no
Skin irritant	yes	yes
Eye irritant	yes	yes

Appendix 3.1: Statistical analysis of annual rate of increase in yield in Canadian OSR.

The statistical software, Genstat, was used to perform an F-test to compare slopes of two linear regression lines for average oilseed rape yields in the Canadian Prairie provinces of Alberta, Saskatchewan and Manitoba in Figure 3.1. The first regression line was based on yields from 1988 to 1997; the second from 1998 to 2008. The first time period represents conventional oilseed rape production only and the second total production after the introduction of HT varieties. All data was from the Canola Council of Canada. Statistical output is shown below. Slopes of the two time periods were not significantly different from each other with a p-value of 0.009.

GenStat output:

Summary of analysis

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	2	61.13	30.565	10.01	0.009
Residual	7	21.37	3.053		
Total	9	82.50	9.167		

Percentage variance accounted for 66.7
Standard error of observations is estimated to be 1.75.

Appendix 4.1: Data and methods used in calculation of TFP values.

Overview

- Total factor productivity (TFP) expressed the output of an agricultural system per hectare as a function of the inputs of the system. Outputs mainly included yield and inputs included: on farm costs (land, seed, labour, machinery, fertilizers, crop protection agents) and costs to the environment. All components were expressed in monetary value.
- Data were taken from standard economic references and from published life cycle analysis (LCA) reports on the extent of consumption and environmental burdens resulting from farming in the UK.
- LCA components were converted into monetary units in order to express them on a single, economic basis.
- Direct costs for the production of agricultural chemicals are not included in the analysis because they are included in the price paid by the farmer and thus appear in the denominator of the TFP index (contrary to the norm for LCA calculations).
- Indirect environmental costs, associated with chemical and machinery production or the construction of buildings, are less easy to attribute and were based on the LCA analysis of Williams et al. (2006a).

Primary energy

- Fixed values for direct energy costs for farm operations used were the same as those used in Glendining, for fuel and electricity.
- The energy used for manufacturing fertilisers, biocides or machinery for arable costs is indirectly implied by their cost. The consumption of primary energy is thus limited to operational costs such as fuel to power tractors or the drying of harvested grain. On the other hand, environmental emissions associated with manufacture were given environmental costs using the emission values per unit input from Williams et al. (2006) and the costs of Pretty (2000, 2005).

Crop protection agents

- Economic cost and environmental cost of applying these chemicals (primary energy, etc.)
- Yield of GM and conventional systems was assumed to be the same despite different quantities of biocides applied.

REVENUE

1) Oilseed rape Yield

All revenue accounted for came from OSR seed sales. Revenue received by the grower used was 400$/tonne of produce for all systems. Actual commodity prices for 2009 taken from standard publications do not differ considerably (Table A-1). Yields used were representative of typical yield for 2009 in the two locations and yield used for GM and conventional systems in Canada were assumed to be the same.

OSR straw was assumed to have no sale value and no subsidies were included in either case. The KWIN includes 100 euros per hectare of revenue from straw sales, however in Canada residues are normally left on the field (in zero-tillage, or incorporated in plough-based fields). Therefore for comparison purposes straw had no sale value. Glendining made the same assumption.

Table A-1. Standard revenue data, based on 2009 prices.

	Location	Value (US$/tonne)	Source
Oilseed rape seed	the Netherlands	400	KWIN 2009
	western Canada	407	Statistics Canada. Cereals and Oilseeds Review - December 2009

ON FARM COSTS

On farm consisted of costs that are incurred either directly or indirectly by the farmer, excluding environmental costs. Some of these costs are dependent on yield, for example seed drying costs, while others are dependent on inputs, such as cost of crop protection agents.

1) On-farm Energy

This component accounted for energy costs to the farmer, either directly or indirectly using data from Williams et al. (2006) for oilseed rape. Direct energy accounted for use of diesel or electricity in farm operations. However, these costs consisted of the total amount of energy to carry out the operation (operation energy), multiplied by the 'energy factor' for the energy source. This is the energy required to transport the fuel to the farm or, in the case of electricity,

to produce the electricity. Diesel has an energy factor of 1.1, electricity of 3.6. Costs of diesel were based on the assumption of 35.5 MJ/L of diesel and a fixed cost for diesel (Table A-2). Energy requirements to manufacture farm buildings was not included. In addition, depreciation of machinery and other equipment was not taken into account.

Table A-2. Resource costs.

Resource		Price (US$)	Units
Diesel		0.58	1 L
Electricity		0.000248	1 L
Seed		18.87	1 kg
Fertilizer			
	N	0.69	1 kg N
	P	0.23	1 kg P
	K	0.32	1 kg K
	S	0.28	1 kg S

Operational Energy

Direct or operation energy use (mainly diesel) was either fixed per hectare, or yield dependent expressed in MJ per pass, or per tonne, as appropriate.

a) Cultivation operations

This was the energy cost of sub soiling and seed bed preparation; ploughing, rolling, harrowing, and drilling. These costs were directly effected by tillage system and all energy was assumed to come from diesel. Plough-based systems were used in conventional systems and direct drill seeding was used in GM systems (Table A-3).

Table A-3. Energy requirements for cultivation operations paid directly or indirectly by the farmer.

Operation	Tillage method	Energy required for OSR (MJ/ha)
Sub-soil maintenance	All	151
Seed bed preparation	Plough-based	2393
	Reduced tillage	1868
	Direct Drilled	418

b) Harvest operations

There are two types of harvest energy costs included. Those related to yield and those not related to yield. For OSR, the yield independent costs were the energy used in combining (716 MJ/ha), while energy used in carting seed was dependent on yield (15 MJ/tonne produce).

c) Fertilizer operations

The energy used in applying fertilizer. Energy required was based on number of passes with machinery required (75 MJ/pass). It was assumed that P, K and S are applied in the seedbed, or in combination with N, and applications of N fertilizer were applied, in steps of 60 kg N/ha. All fertilizer was applied broadcast.

d) Crop protection operations

Similar to fertilizer operations, use of less fertilizer and biocides logically means less passes on the field. Number of spray operations was also adjusted for amount of herbicide applied. Glendining used an average number of spraying operations per season of 5.1 in the UK. To make operational energy dependent on amount of active ingredient applied, this value was used to determine an estimate of average quantity of active ingredient applied per spray operation (application). Thus, biocide was assumed to be applied at a maximum rate of 0.35 kg a.i./ha per application and this value was used to calculate number of passes (56 MJ/pass). Yield and cultivation method (plough-based, reduced tillage, direct drill) was independent of crop protection applications of all kinds.

e) Post-harvest operations

Harvested OSR seed needs to be dried to 86% DM and kept cool. This was calculated assuming energy use of 25% electricity and 75% fuel oil. Energy requirements are dependent on yield and were 68 MJ/tonne to dry, 0.3 MJ/tonne to cool and 11 MJ/tonne to store as in Glendining.

f) Energy in Production of Fertilizer and Biocides

Although Glendining discussed indirect energy requirements from a study by Williams et al. (2006), ultimately they do not incorporate these environmental costs into TFP and the current study does the same. The cost of energy used in the manufacture of fertilizer and biocide products was indirectly implied in their cost to the grower.

g) Irrigation

OSR fields are not commonly irrigated in the Netherlands or Canada, so this component was not included.

2) Materials and Other On-farm Costs

a) Fertilizer materials

Cost to the farmer of fertilizer products including N, P, K and S (Table A-2). Amount of N applied was 180 kg N for the Netherlands and 110 kg N/ha for Canada. Amounts of P, K and S were based on the same nutrient requirements for OSR used by Glendining per tonne of yield: 6.2 kg P/tonne, 9.1 kg K/tonne, and 7.0 kg S/tonne.

b) Crop protection materials

Quantity of biocide applied for the Netherlands was taken from the KWIN 2002. Corresponding values came from the Prairie Weed Management Survey for GM and conventional fields in Canada. Cost of biocide to the farmer for the Netherlands was obtained directly from the KWIN 2009. Since costs for biocide could not be directly obtained for Canada, those from the Netherlands were used as estimates. A weighted average was used for each type of biocide to estimate average cost of herbicide, insecticide and fungicide in Canada. A weighted average was used because there are large variations in price of crop protection agents and logically, the most expensive chemicals will be used at the lowest quantities. Herbicide, insecticide and fungicides were accounted for.

Glyphosate tolerant OSR was chosen to represent GM systems in Canada. Of the three major HT OSR varieties grown, glyphosate tolerant cultivars make up over 50% of cultivated area (Leeson et al. 2006). Glendining based amount of biocide on number of products applied and assumed that extra herbicide products were applied when cultivation was reduced (one extra for reduced tillage and two extra for zero-tillage). Since average use data on quantity of biocide active ingredients applied was available for all systems, this assumption was not necessary.

c) Seed costs

Fields in both the Netherlands and western Canada were assumed to be seeded at 4.0 kg/ha. Seed costs were taken from the KWIN and assumed to be the same in both countries (Table A-2; R. Karamanos, *personal communication*). Seed costs most often include cost of seed treatment with biocide, however environmental costs of seed treatments were assumed to be negligible.

d) Fixed costs

For a full economic analysis of production, fixed costs for an operation were also required. These vary considerably from farm-to-farm, depending on size and type of operation, region, intensity of farming, etc. Glendining used average values from the standard British publication Nix (2005), and we have used these values for all costs, with the exception of land rental value in Canada (19.24 US$, Statistics Canada). All values are whole farm average figures for large sized enterprises (200 ha plus). Fixed costs per hectare tend to be more for smaller and less for larger operations. Energy costs (mainly diesel and electricity) were not included, as these were already included as a variable cost. Labour included both regular paid labour and unpaid family labour, including that of farmer and spouse (Table A-4).

Table A-4. Total whole farm fixed costs for oilseed rape (OSR) and potatoes (US$/ha).

	OSR	Potatoes
Regular labour (paid)	140.25	206.25
Regular labour (unpaid)	66.00	49.50
Casual/contract labour	16.50	variable
Total labour*	222.75	255.75
Machinery depreciation	123.75	148.50
Machinery repairs	66.00	86.63
Contract	57.75	90.75
Vehicle tax and insurance	12.38	16.50
Total power and machinery	259.88	342.38
Land rent, rental value	231.00	264.00
General overheads	107.25	115.50
Total fixed costs	**820.88**	**977.63**

*Labour costs without adjustment for zero-tillage practices.
Converted from British pounds at a rate of 1£ = 1.65 US$. Based on Nix (2005).
Potatoes included for comparison purposes only.

Lastly, a cost of 1.86$/ha was added to fixed on farm costs for monitoring and advice. These costs may include: biocide residue and nutrient monitoring in food and the environment, and for administration of integrated pest management and/or nutrient management schemes. This estimate was based on Pretty's (2005) value of £13.1m for monitoring and advice on biocides and nutrients across the UK.

Adjustment in labour costs for zero-tillage systems

A benefit of GM OSR often mentioned is the adoption of zero-tillage practices. Resulting changes to farm operations included in Glendining's analysis were reduced fuel consumption and GHG emissions. Presumably, zero-tillage practices would also represent savings in labour costs, however this was not considered by Glendining. In the current analysis, some calculations were made to account for savings in labour costs for zero-tillage practices (Table A-5). Calculations were made assuming it took 100 minutes to plough 1 hectare (plough-based tillage). Number of passes used for each tillage method was the same as that provided by Glendining's estimates of costs to the environment. Wage per hour of labour was 15 US$/hour (approximately minimum wage plus 50%). The value of labour saved by adoption of zero-tillage practices was included in GM systems, except when otherwise specified.

Table A-5. Estimation of value of labour savings associated with zero-tillage practices (US$/ha).

	Zero-tillage	Plough-based tillage
# of passes/ha*	2.33	6.34
Hours required per hectare (hours/ha)	0.61	1.67
Wage (US$/hour)	15.00	15.00
Total wage per hectare (US$/ha)	9.19	25.00
Value of labour savings with zero-tillage practices (US$/ha)		15.81

*Source: Glendining et al. (2009).

ENVIRONMENTAL COSTS

These are the costs which are not directly borne by the farmer, but by the environment and society. Much of the data used by Glendining was from the various studies carried out by Pretty and colleagues for the UK (Pretty et al. 2005, Pretty et al. 2000, Pretty et al. 2003) as well as Atkinson et al. (2004). These estimates for the UK were applied to both the Netherlands and Canada. All values in Table A-6 are expressed in British pounds, but were converted to US dollars for this study.

Table A-6. Costs assigned to environmental impacts from agriculture in the UK.

Environmental burden	Total cost to UK in 2000 (£ million)	Source
Crop protection		
Removal from drinking water	143	Pretty et al. 2005
Damage to human health (acute effects)	1.2	Pretty et al. 2005
Pollution incidents (50% of total £6m)	3	Pretty et al. 2000
Damage to natural capital, loss of biodiversity and landscape, including bee colonies (50% of total costs of £150.3m)	75.2	Pretty et al. 2005
Total crop protection costs	222.4	
Nitrogen		
Removal of nitrate from drinking water	16	Pretty et al. 2000
Eutrophication due to nitrate leaching	34-55	Pretty et al. 2005
Loss of biodiversity and landscape due to use of N fertilizer (assumed to be 10% of total costs)	15	Glendining et al. assumption of 10% of value from Pretty et al. 2005a
Phosphorus		
Removal of phosphate from drinking water	32.8	Pretty et al. 2000, 2005
Eutrophication due to leached phosphate (see text below)	24-45	Pretty et al. 2005, Glendining assumptions on%

Loss of biodiversity and landscape due to use of P fertilizer (assumed to be 10% of total costs)	15	Glendining et al. assumption of 10% of value from Pretty et al. 2005
Emissions of greenhouse gases		
Methane (from livestock)	£77.9/t CH4	Pretty et al. 2003
	£400/t CH4	Atkinson et al. 2004
Nitrous oxide (from fertilizers)	£2961/t N2O	Pretty et al. 2003
	£5588/t N2O	Atkinson et al. 2004
Carbon dioxide (from fossil fuels)	£29.8/t C	Pretty et al. 2003
	£70/t C	Atkinson et al. 2004

a) Environmental Costs of Biocides

The estimated environmental impact of the use of biocides was calculated as the sum of the cost of removal of compounds from drinking water, cost to farmers and the National Health Service of acute damage to human health, and the cost of the loss of biodiversity. Pretty et al. (2000, 2005) estimated environmental costs of chemicals for the whole of the UK. For example, this analysis used costs of biodiversity losses estimated by Pretty et al. (2000). They used costs of restoring species and habitats under the Biodiversity Action Plans (BAPs) of the UK to estimate costs of wildlife and habitat losses. For species and habitats for which agriculture was identified as one of the causal agents, half of the costs of actions to protect and restore biodiversity was attributed to agriculture and used in these analyses.

This cost was partitioned by Glendining into estimates of environmental impact from each crop species based on their relative production rates and on typical range of sprays used with each commodity. The impact associated with the energy required to apply biocides was accounted for elsewhere.

Using a total of 22.5 million kilograms of active ingredient applied to UK agriculture and the total cost of use of crop protection agents to the environment in the UK, Glendining calculated a cost to the environment of £9.88/kg of active ingredient (16.30 US$/kg a.i.). The estimate of total quantity of active ingredient applied used by Glendining was from 1998, but was the most recent value available, as it is not assessed regularly.

Assumptions:

- All crop protection products applied to agriculture are assumed to have an equal environmental burden. This is certainly not the case, as the individual chemical properties of a biocide will determine its effect on the environment, as well as its mobility and persistence. This also assumes that impact of biocides is linearly related to quantity of active ingredient applied.
- Cost of seed treatments to the environment were not accounted for. Seed treatment was included in the cost of seed to the farmer, but environmental impact of the seed treatment was not included.
- Energy used in manufacture and transport of biocide was not included as these costs were assumed to be accounted for in retail value of the product to the farmer. Environmental costs of biocide manufacture were included.

b) Cost of Field Nutrient Losses

Adverse environmental effects due to the application of nitrogen fertilizer included effects of nutrient leaching (eutrophication and loss of biodiversity and wildlife) and emissions of the greenhouse gas N2O (see part c). The only nutrients included were nitrogen and phosphorus. Similar to biocides applied energy used in manufacture of fertilizer was not included, but environmental costs of fertilizer manufacture were included.

i) Nitrate and Phosphate Leaching

Nitrate leaching is difficult to estimate, although a few studies have attempted to do so. In this study and Glendining used an estimate of nutrient leaching on arable fields from Goulding 2000 to estimate leaching rates. Estimates of N and P field losses were based on two parts: constant background N mineralization from soil organic matter and direct losses of fertilizer dependent on amount of fertilizer applied and crop species. For OSR, the nitrogen background mineralization factor used was 17 kg N/ha/year, and for phosphorus 1.0 kg P/ha/year (not specific to OSR). Rate of nitrogen loss per kg N applied was: 0.13 kg N/kg N applied, below fertilizer applications of 230 kg N/ha (Table A-7). This level was estimated as a breakpoint, above which rates of nitrogen field loss increase greatly to 0.70 kg N/kg N applied, however rates applied in the cases of interest for this study fell below this point. Rate of phosphorus loss used was 0.1 kg P/kg P applied, and phosphorus applied was assumed to equal the amount required by OSR (6.2 kg P/tonne of produce).

Table A-7. Relationship between nitrogen fertilizer applied and nitrogen (N) leached.

Crop	Percentage of leachable fertilizer N		Breakpoint (kg N/ha)	Background N leached (kg N/ha)
	< breakpoint	> breakpoint		

OSR	13	70	230	17
Potatoes	22	80	185	17

Data from (Davies and Sylvester-Bradley 1995; Lord 1992).
Potatoes included for comparison purposes only.

Assumptions:

- Glendining have estimated total nitrate leaching from data on leaching from arable crops and grass grown under 'good nitrate practice', scaled up for the whole of the UK (Goulding 2000), to obtain total losses of 472,598 tonnes N/year.

ii) Cost of Nitrate and Phosphate Leaching

The estimated environmental impact of the use of N and P lost from fields was calculated as the total of the cost of eutrophication and the cost of biodiversity loss. Costs of N and P loss used were the same as Glendining (Table A-8).

Eutrophication

Eutrophication was assumed to be primarily caused by nitrogen and phosphate. The main agricultural sources are nitrate and phosphate leaching, and ammonia emissions, but for simplicity, Glendining assumed that all eutrophication arising from N additions to agriculture was due to nitrate and phosphorus additions to agriculture and these costs included the removal of the nutrients from drinking water, loss of biodiversity and habitat, costs associated with the appearance of algal blooms that diminish the value of water-side properties, recreation, and the tourist trade.

Loss of biodiversity from N additions

Pretty et al. (2000, 2005) estimate the costs of damage to natural capital - loss of biodiversity and wildlife, including bee colonies, and landscape values to be £150.3m based on costs of restoring species and habitats under the Biodiversity Action Plans (BAPs) of the UK. Glendining assumed that the use of nitrogen and phosphorus fertilizers accounted for 10% each of this cost. Another 50% of this cost was assumed to be due to use of biocides (£75.2m).

Table A-8. Cost of nitrogen and phosphorus loss from agricultural fields.

Nutrient		Cost of nutrient loss per kg applied (US$/kg)
N	Leaching of applied fertilizer (water clean up and eutrophication potential)	0.2145
N	Loss of biodiversiy	0.01815
P	Leaching of applied fertilizer (water clean up and eutrophication potential)	9.24
P	Loss of biodiversiy	0.198

c) Cost of Field Emissions

Costs associated with N2O emissions from nitrogen fertilizer application were calculated separately from other GHG emissions. This value plus additional emissions from field operations, storage, manufacturing, and application of fertilizers and crop protection agents together gave total GHG emissions.

Environmental costs from each type of GHG from Atkinson et al (2004) were used:

- CH4 was 660 US$/tonne CH4 (£400/tonne),
- N2O was 9220.2 US$/tonne N2O (£5588/tonne),
- and CO2 was 115.5 US$/tonne (£70/tonne C).

These costs represent economic costs of global warming (originally from Eyre et al. 1997), deemed by the UK government to have used the most sophisticated methods to date out of many studies reviewed.

Cost of N2O from fertilizer application was combined with information from Project ISO205 (Williams et al. 2006) on the amount of CO2, CH4, and N2O emitted by fuel used in field operations, etc. to calculate total greenhouse gas emissions. CO2 emissions from soil due to cultivation was not included in concurrence with Glendining. Due to the large costs used for the various GHGs, small changes in the estimated emissions could have large effects on environmental costs.

Quantity of N2O emissions (emission factor) varies depending on type of N fertilizer used (% of applied N for each type of fertilizer used). Glendining used average proportions of the different types of fertilizer used on OSR in the UK plus a background emissions of 1.0 kg/ha (Table A-9; Brown et al. 2002). For OSR types of fertilizer most commonly applied were 53% ammonium nitrate, 16%, urea, 1% urea ammonium nitrate and 21% others.

Table A-9. Average type of nitrogen fertilizer applied to oilseed rate in the UK and corresponding emission factors.

Type of N fertilizer	Proportions of types of fertilizer used on OSR (in UK)	N2O emission factor (% of applied N)
Ammonium nitrate	0.53	0.008
Urea	0.16	0.011
Urea ammonium nitrate	0.1	0.010
Others	0.21	0.008
Background Emissions (1.0 kg/ha)	-	1.000

d) Environmental Costs from Farm Operations

Costs to the environment of farm operations mainly consisted of GHG emissions from tractor diesel burned in various practices. In addition, energy and GHGs produced during machinery manufacture were included through LCA. Farm operations included in this study were: application of fertilizer and biocide, cultivation, harvesting, and crop storage and drying. Cost of cultivation operations was based on number of passes for each type of machinery in plough-based, reduced tillage and zero-tillage systems. Fertilizer and biocide application costs were also based on number of passes required. All operational costs were determined by Glendining using LCA values from various studies by Pretty et al.

Crop Harvest, Storage and Drying

Cost of harvesting, carting, storing and drying seed was dependent on yield (Table A-10). Harvesting included tractor diesel and machinery manufacture. In all situations in the present study, straw was assumed to be either incorporated into soil or left on fields, but costs of baling and loading straw could be incorporated if necessary.

Table A-10. Environmental cost of harvest, storage and drying operations for oilseed rape (per tonne of produce) determined using life cycle analysis (LCA).

Farm Operation	Cost to Environment (US$/tonne seed)
Combining	11.65
Grain carting	0.24
Crop storage and drying	0.98
Baling	3.77
Straw bale carting	0.24
Bale loading	0.25

Cultivation

Applicable environmental costs for cultivation practices were dependent on the tillage system used. Glendining expressed all costs per pass of machinery, type of machinery used and number of passes was dependent on tillage system (Table A-11). Zero and reduced tillage systems were assumed to use direct drill seeding, while plough-based systems used conventional drilling. For fertilizer and biocide application, number of passes was dependent on amount of these products applied as calculated previously for on farm costs (see part 1c and 1d).

Table A-11. Environmental cost of cultivation operations and application of fertilizer and crop protection agents determined using life cycle analysis (LCA).

Machinery	Cost to Environment per Pass (US$/ha)	Number of passes		
		Plough-based	Reduced Tillage	Zero-tillage
Cambridge rolls, 6m	2.26	2	1	1
Combination drill, 6m	13.52	-	1	-
Conventional drill, 6m	3.09	1	-	-

Direct drill, 6m	4.02	-		1.13
Disc & pack, 5.5m	5.78	1.5		-
Heavy discs 5.5m	8.23		0.5	-
Plough, 8 furrow	15.32	1.13		-
Power Harrow, 4m	10.43	0.51	0.5	-
Spring Tine harrows, 6m	3.35		1	-
Subsoiler, 3 legs for tramlines	1.92		1	-
Subsoiler, 7 legs for normal cultivation	12.25	0.2	0.2	0.2
Fertilizer application	1.22	Dependent on amount of fertilizer applied (total kg N fertilizer/60 kg N per application+1).		
Application of crop protection agents	0.91	Dependent on amount of biocide applied (0.35 kg a.i./ per pass).		

e) Environmental Value of Land

Land was converted to financial values based on the concept of ecosystem services outlined by Constanza et al. (1997) (Table A-12). The more ecosystem services provided by the land use, the greater its value per hectare. Glendining took land area used in production in account because, although a less intensive system may pollute less on a per hectare basis, it requires more land area to produce the same amount of food. Thus, extra land needed to produce food with less pollution has a cost associated with it.

- Cropland, grassland and temperate forest were given values for their environmental benefit, but value of food and fibre production was discounted because this residual benefit, for say cropland, is attributed to production in this analysis; that is to say it has been included elsewhere.
- Cost of bringing land into crop production is taken as a cost to the environment.
- The value of renting or owning land was also included as an on farm costs.

For the Netherlands loss of ecosystem services was accounted for by the conversion of temperate forest into agricultural land. This value was the same as that used by Glendining. In the case of the Prairies, calculations were based on ecosystem services for grassland and as a result were less that those for the Netherlands (Table A-12).

Table A-12. Value of ecosystem services for different biomes, less the value of food and raw material production (Costanza et al. 1997).

Biome	Ecosystem service value (US$/ha)
Temperate forest	227
Grassland	165
Cropland	73