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The Value of Plant Science Innovations to Canadians

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CropLife Canada

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Executive Summary

This report examines the economic, environmental and social benefits and value that the plant science innovations deliver to Canadians. Plant science innovations include both pest control products and products of modern plant breeding that together are used to support and advance sustainable agriculture through crop production improvement.

Crop and food production is essential to Canada's economy and to Canadians' well-being. And the plant science sector in Canada plays a key role, generating a significant number of jobs and income for Canadians, helping to ensure an abundant food supply in Canada and for export markets, and enhancing Canadians' access to fresh, locally produced food across the country. Plant science has also played a critical role in improving sustainable agricultural practices, by way of reducing the amount of tillage, soil erosion, land-use, and green house gas emissions, as well as improving biodiversity and preserving large tracts of forest, native grass and wetlands.

Highlights of this report are summarized below. Further details and references can be found in the full text of the report.

Providing Healthy, Affordable Food to Canadians

Plant science innovations lead to direct savings on the food Canadians eat, and help to ensure that we have a reliable source of affordable, good quality fresh fruit, vegetables and grains that are important to a healthy diet. Without plant science innovations, Canadians could pay about 55% more for their food. On an annual basis, it is estimated that the average Canadian household saves more than $4,400 on their food bill, for a total of over $60 billion in savings on food expenditures for all Canadians each year.

Increasing Agricultural Output and Incomes for Farmers

Growing crops is a major job and wealth producer in Canada. In the crop production sector, plant science innovations generate over 111,000 jobs and $8.3 billion in additional agricultural output in Canada. This increased output from plant science innovations also accounts for 71% of Canada's positive trade balance in crops.

The key is the additional yields and quality attained by farmers, accounting for over $7.1 billion in the value farmers receive for their field crops; approximately $353 million in the value of fruit crops; $434 million in potatoes and $435 million in other vegetable crops. Overall, the increased agricultural output from plant science innovations generates more than $7.5 billion in GDP for Canada, which is comprised of $4 billion in added value by Canadian farmers, and $3.5 billion in added value from increased business for suppliers to Canadian farmers.

Generating High Value R&D and Manufacturing Jobs

Plant science companies spend annually $230 million on R&D in Canada, generating about 4,000 high-value, science-based jobs for Canadians. The total economic impact from manufacturing and production of plant science products accounts for over $1 billion in added value to Canada's economy, 9,000 jobs and $467 million in income for Canadian workers.

Creating Jobs and Growth for All Canadians

Overall, plant science innovations have significant impacts throughout the Canadian economy, generating a total of almost $9.8 billion in GDP, $4.7 billion in income and over 131,000 jobs for Canadians. This economic activity also delivers over $1.8 billion in tax revenues to governments across Canada.

Preserving Land

Plant science innovations have allowed us to preserve a large swath of Canada's land as forest, wetlands and native grass areas. Without these innovations, Canada's agriculture area would need to be 50% larger to produce the same level of crop production.

The productivity improvements provided by plant science innovations has allowed us to preserve and leave uncultivated over 14.2 million hectares (35.1 million acres) of forest, native grass, wetlands, etc. (14.2 million hectares is equal to the total area of crops grown in Saskatchewan, or four times that of Ontario). The productivity gains for Canada have been greatest in the areas of field crops such as canola, wheat, soybeans and corn.

Protecting Biodiversity

Plant science innovations contribute to biodiversity by reducing the amount of land devoted to agriculture and limiting encroachment on non-agricultural land, thereby helping to preserve wildlife habitats, such as forest, wetlands and grasslands. They also help to address invasive plant species such as weeds and fungi that have a negative impact on wildlife habitats.

Modern plant breading technologies such as drought and salinity tolerance are expected to further alleviate the pressure to convert high biodiversity areas into agricultural use, and plants with increased nitrogen use efficiency are also under development that reduce run-off of nitrogen fertilizer, which will help to protect wildlife habitats and water quality.

Recent studies have also shown that plant science innovations have improved agricultural practices, resulting in significant reductions in soil erosion and improved soil quality across a range of crops in Canada.

Conserving Water

No-till agriculture results in significantly higher soil water conservation, which can greatly reduce the need to irrigate in semi-arid and arid crop growing conditions. This is important in Alberta where semi-arid plains require much more irrigation than the rest of the country. Between 1991 and 2012, Alberta experienced a 28% decrease in the amount of water used for irrigation, while the area using no-till agriculture increased from 3% in 1991 to 65% in 2011. This increase in no-till agriculture was enabled by the use of plant science innovations, and directly contributed to the reduction in irrigation in Alberta.

Dealing with Climate Change

Since 1990, the reductions in tillage owing to the use of plant science innovations have resulted in a 3.8 fold increase in carbon sequestration in cultivated land, reducing greenhouse gases (GHGs) by about 4 million tonnes per year. Decreases in summer fallow add another 5.2 million tonnes of GHG reductions through carbon sequestration.

The use of plant science innovations has also resulted in 126 to 194 million less litres of diesel fuel burned on-farm each year owing to reduced tillage and reductions in the number of equipment passes on land, reducing GHG emissions by about 450,000 to 700,000 tonnes per year.

Most importantly, if plant science innovations were not employed in agriculture, farmers would need to cultivate 50% more land to produce the same amount of crops. This would have a severe impact on the amount of carbon sequestration in soil, and would also significantly increase the amount of fuel use for planting and cultivation.

Overall, the total annual GHG reduction from the use of plant science innovations in agriculture is estimated to be 29 million tonnes per year. This represents 4% of the 726 million tonnes in total GHG emissions for Canada in 2013. While Canada’s total GHG emissions have climbed by 3.8% since 2009, continued adoption of plant science innovations in the future will enable farmers to further reduce GHG emissions in the agriculture sector to help offset potential increases in other sectors of Canada’s economy.

As we face the challenges associated with climate change, there will be a need for faster crop improvement programs to develop plant varieties that are well adapted to new climates and growing conditions. Modern plant breeding techniques are being used to speed the process for developing new plant varieties that will better withstand drought conditions, and contribute to even greater sequestration of CO_2 and lower CO_2 emissions by reducing tillage, conserving soil and moisture.

Delivering Other Environmental Benefits

As research progresses, farmers in Canada have been able to employ plant science products that have less toxicity and environmental impacts than previously. In addition, greater innovative production also means less pressure for Canadian farmers to plough fragile marginal lands that are less suitable for crop production.

Producing Significant Benefits for Canadians

Canadians enjoy significant economic, environmental and social benefits from plant science innovations. In addition to the 131,000 jobs and $4.7 billion in income for Canadians generated by plant science innovations, the annual value to Canadians of lower food prices, reduced GHG emissions and added value to the Canadian economy is estimated to be more than $70 billion. This represents a benefit of $2,000 to each Canadian per year.

1. The Plant Science Sector in Canada

1.1. What is Plant Science?

Plant science innovations include both pest control products and products of modern plant breeding that are used to support and advance sustainable agriculture through crop production improvement.

A ***pest control product*** is any product intended to control, destroy, attract or repel any pest, and includes chemicals, devices (such as pheromone traps) and even organisms (such as microbials). According to Health Canada (2015a), the most common pest control products are herbicides (almost 64% of all pest control products sold in Canada, by volume), antimicrobials (19.7%), insecticides (5.1%) and fungicides (8.4%). While pest control products are most commonly synthetic products, the term also includes biopesticides derived from such natural materials as animals, plants, bacteria, and certain minerals. Biopesticides account for more than 6.4% of all pest control products.

Overall, agricultural use accounts for 78% of all pest control product use by volume. The non-agricultural sector (e.g. mainly antimicrobials used for wood preservation and water treatment, as well as some herbicides used in industrial vegetation management) has a 17% share of pest control product use, while domestic use (e.g. mainly antimicrobials used for swimming pool and spa treatment, as well as insecticides and herbicides) accounts for just under 5%.

Modern plant breeding is a multi-disciplinary process that involves conventional breeding techniques, bioinformatics, molecular biology and recombinant DNA (rDNA) driven genetics. For thousands of years, plant breeders used "conventional breeding" or "selective breeding" techniques to create distinctive cultivars or varieties of plants with specific traits, yield increase characteristics, herbicide tolerance for weed control and disease resistance, modified oil profiles, etc. However, with conventional plant breeding, many crosses and selection cycles are required to obtain the particular trait or gene combination, with no guarantee of success. With conventional plant breeding, undesirable genes can be transferred along with the desirable traits; or while one desirable gene is gained, another is lost because the genes of both parents are mixed together and assorted randomly in the offspring. These technical challenges limit the improvements that plant breeders can achieve through conventional breeding techniques.

To address these technical challenges, in recent decades conventional plant breeding techniques have been supplemented with modern plant breeding techniques that include:

- Tissue culture and micro-propagation
- Molecular breeding, or marker and genomics assisted selection

- rDNA-driven genetic engineering (GE), living modified organisms (LMOs) or the genetic modification (GM) of crops (also known as GMOs for genetically modified organisms), although fundamentally all plant breeding is essentially genetic modification
- Molecular diagnostic tools

Another technique used in modern plant breeding is mutagenesis, a process by which plant breeders alter a plant's genes by the use of chemicals or radiation, followed by the selection of the desired variants to introduce into conventional breeding programs to create new varieties.

1.2. Production of Plant Science Products in Canada

Total revenues for the plant science sector in Canada were estimated to be about $4.2 billion in 2013, with sales of pest control products accounting for $2.2 billion of the total, and products of modern plant breeding (seeds) totalling $1.99 billion.

Table 1: Estimated Sales by the Plant Science Sector in Canada, by technology ($000)

	2010	2011	2012	2013
Pest Control Products	$1,470,000	$1,460,000	$1,700,000	$2,200,000
Modern Plant Breeding	$760,000	$920,000	$1,000,000	$1,990,000
Total Plant Science Sector	$2,230,000	$2,380,000	$2,700,000	$4,190,000

Sources: CropLife Canada Annual Reports, 2009-10 to 2013-14

Additional information on the sector has been drawn from Statistics Canada and Industry Canada. Within Statistics Canada and Industry Canada definitions, pest control products are captured under the North American Industrial Classification System (NAICS) code 32532 - Pesticide and Other Agricultural Chemical Manufacturing. .

Table 2 below provides a summary of the market for all pest control products in Canada, showing manufacturing revenues, exports and imports. The total market for pest management products in Canada (apparent domestic market) is calculated as manufacturing revenues less exports plus imports.

Table 2: Pest Control Products in Canada ($000)

	2008	2009	2010	2011	2012
Total revenue	$877,049	$991,274	$890,277	$497,161	$581,378
Revenue from goods manufactured	$868,755	$975,760	$881,827	$489,779	$560,557
Exports	$107,936	$118,890	$104,629	$84,580	$90,452
Imports	$1,147,000	$1,302,000	$1,094,000	$999,000	$1,160,000
Total Pest Control Product Market	$1,908,000	$2,159,000	$1,871,000	$1,404,000	$1,630,000
Number of establishments	37	35	34	(T)	(T)

Sources: Statistics Canada. Table 301-0006, Industry Canada – Trade Data Online. NAICS 32532 - Pesticide and Other Agricultural Chemical Manufacturing. Note: "T" - terminated data.

Revenue from pest control product manufacturing in Canada totaled $560 million in 2012. Canada is a net importer of pest control products; importing $1.16 billion in 2012. Data related to this NAICS code includes pest control products not used in crop production, such as antimicrobials and rodenticides. Despite this, values for the Total Pest Control Market in Table 2 are close to the estimated sales of pest control products by CropLife Canada members shown in Table 1.

Unfortunately, there is very little data available on products of modern plant breeding from Statistics Canada, Industry Canada or Agriculture and Agri-Food Canada (AAFC). To determine domestic production of products of modern plant breeding technology, we based our estimate on domestic production of commercial seeds calculated by the George Morris Centre (GMC 2014) for AAFC's Seed Value Chain Roundtable.

In their report, GMC estimated that total commercial seed sales of $1.8 billion were comprised of $328 million in imports, and total domestic production of seeds valued at $1.47 billion. We scaled GMC's $1.47 billion estimate for domestic commercial seed production to domestically produced seeds from modern plant breeding on the basis of the seeded acreage for the crops employing modern plant breeding technology, as shown in Table 3. This is necessary as currently data does not exist on the proportion of domestic seed production developed from modern plant breeding techniques other than GE and mutagenesis. Many of the other modern breeding tools used by the industry, such as marker and genomics assisted breeding, are very widely deployed but are not measured. Therefore this report only reflects what is currently measured and therefore the scaling unfortunately does not capture the full value of products of modern plant breeding.

Table 3: Estimate of Domestic Production of Seeds from Modern Plant Breeding, 2012

Crop	Seeded Acreage 2012	% of total Crop Acreage	Estimated Sales of Domestic Commercial Seeds ($ millions)	% of Crop Planted with Modern Plant Breeding Technology	Estimated Sales of Domestically Produced Seeds from Modern Plant Breeding
Canola	8,911,700	23.3%	$341,558,000	99%	$338,399,000
Corn	1,717,600	4.5%	$65,830,000	98%	$64,562,000
Lentils	1,017,700	2.7%	$39,005,000	80%	$31,228,000
Soybean	1,680,400	4.4%	$64,404,000	83%	$53,496,000
Sugar beets	10,100	0.0%	$387,000	96%	$372,000
Sunflowers	40,500	0.1%	$1,552,000	20%	$311,000
Wheat	9,630,300	25.1%	$369,099,000	3%	$11,081,000
Sub-total					**$499,449,000**
All Crops	38,325,200		$1,470,000,000		

Source: Statistics Canada, CANSIM Table 001-0010 and GMC 2012.

Based on this approach, the value of Canadian production of seeds from modern plant breeding is estimated to be $500 million in 2012.

Effective Management of the Sector

The plant science sector is a cutting-edge, high-tech industry that is subject to comprehensive and rigorous regulatory scrutiny by governments to ensure safeguarding of human health and the environment. Beyond the strict legal requirements to which the sector must adhere, the industry has voluntarily introduced comprehensive stewardship practices to ensure sustainable and responsible best-practices are followed. For more information on regulation and stewardship practices of plant science sector, please refer to Appendix 2.

2. Measuring Benefits to Canadians

Measuring benefits to society generally involves three (3) measures of sustainability – economic, environmental and social impacts. These three measures are consistent across the literature assessing the overall impacts of industries.

Economic Benefits

This study estimates the amount of economic activity that is generated throughout the Canadian economy by the production, sale and use of plant science innovations in Canada using Statistics Canada's input-output model (IO model). IO models are the most accepted tool to provide insight into the complex economic interrelationships between industries and demand. The economic impacts derived from IO models fall into three subcategories:

a) Direct economic impacts - the changes to the economic indicators within the sector as a direct result of production.
b) Indirect economic impacts – the changes to the economic indicators as a result of changes in production of suppliers in order to meet demand in the plant science sector.
c) Induced economic impacts – the economic impacts that result from higher household spending as a result of higher wages and employment.

The three economic indicators presented in this paper are changes in GDP, labour income and employment. The results of our analysis of economic impacts across the value chain can be found in Section 3. Additional details on the analytical methodology can be found in Appendix 3 - Measuring Economic Impacts.

Measuring Benefits to the Environment

When pest control products were first introduced, yields improved dramatically, kicking off the "green revolution" that took place between the 1940s and late 1960s when substantial increases in global agricultural productivity took place. More recently, further advancements in pest management and modern plant breeding have changed agricultural practices and the profile of products used (development of products with lower toxicity/environmental impact) that, along with integrated pest management and conservation tillage practices, have led to additional yield gains. Section 4 examines the impacts of plant science innovations on yield, biodiversity, soil quality, land-use, water use, fuel use, and greenhouse gas emissions.

Measuring Social Benefits

Impacts on Canadian consumers are examined and quantified, and other benefits to society are examined in Section 5.

3. Economic Impacts of Plant Science Innovations

3.1. Economic Impacts of the Plant Science Sector

The testing, development, production and selling of crop science innovations impact Canada's economy at various stages of the value chain. This section includes a breakdown of the economic impacts for the following stages of the value chain:

- Production of plant science innovations (i.e. production by CropLife member companies)
- Suppliers of products and services used in the production of plant science innovations (e.g. R&D, other inputs such as energy, commodity chemicals, financial and professional services, etc.)
- Wholesaling and distribution of plant science products
- Agricultural production using plant science innovations (impacts on other users of plant science products are discussed, but not quantified), and
- Food processing

Production of Plant Science Innovations

Production impacts come from the Canadian production of crop protection products and seeds from modern plant breeding. The following economic impact estimates are based on $560 million in crop protection product manufacturing shipments and an estimated $500 million in production of seeds with novel traits in 2012.

Table 4: Economic Impacts from Production of Plant Science Innovations

	GDP ($ millions)	Labour income ($ millions)	Jobs
Direct			
Pest Control Products	$263	$56	781
Modern Plant Breeding	$229	$59	2,119
Sub-Total	**$491**	**$115**	**2,900**
Indirect and Induced			
Pest Control Products	$407	$218	3,562
Modern Plant Breeding	$265	$135	2,558
Sub-Total	**$672**	**$353**	**6,120**
Direct, Indirect, and Induced			

	GDP ($ millions)	Labour income ($ millions)	Jobs
Pest Control Products	$669	$274	4,344
Modern Plant Breeding	$494	$193	4,676
Total	**$1,163**	**$467**	**9,020**

Canada's production of plant science innovations has a significant impact on the economy. The $1.06 billion in production (which includes some pest control products for non-agricultural use) generates $1.1 billion in GDP, $467 million in income and 9,020 jobs.

Private Research and Development

To bring a new pest control product to market takes up to 10 years and USD $256 million. On average, the plant science industry reinvests about 7% of its total sales into R&D for pest control products. To bring a modern plant breeding product globally to market takes up to 13 years and USD $136 million. Internationally, the plant science industry reinvests 11% of its total sales into R&D (Phillips McDougall, 2012).

Applying the global R&D spending estimates to sales of plant science innovations in Canada, we estimate that Canada's plant science innovation companies spend approximately $230 million on research and development in Canada. This figure is in line with AAFC estimates that R&D spending in 2012 on seeds from modern plant breeding was $110 million on $1 billion in sales in Canada.

Table 5: Economic Impacts of Research and Development[1]

	GDP ($ millions)	Labour income ($ millions)	Jobs
Direct			
Pest Control Products	$130	$108	1,225
Modern Plant Breeding	$79	$66	749
Sub-Total	**$209**	**$174**	**1,974**
Indirect and Induced			
Pest Control Products	$121	$67	1,256
Modern Plant Breeding	$74	$41	768
Sub-Total	**$196**	**$108**	**2,024**
Total Direct, Indirect, and Induced			
Pest Control Products	$251	$175	2,481
Modern Plant Breeding	$154	$107	1,516
Total	**$405**	**$281**	**3,998**

[1] Results in Table 5 are based on IO multipliers for expenditure on research and development are from the "Scientific Research and Development Services Industry".

Private investment in research and development in the plant science innovation industry generated $405 million in GDP, and an additional 4,000 jobs in the Canadian economy, generating $281 million in income.

Warehousing and Distribution

It is important to note that the Statistics Canada IO model bases the economic multipliers on warehousing sales less the cost of goods sold. In the case of agricultural input warehousing and distribution, Industry Canada business financial statistics report that the cost of goods is 83% of agriculture input warehousing and distribution revenues. The output impacts are based on total sales in Canada for the respective plant science innovation industries (including imports):

- Pest Control Products: Total sales in 2012 of $1.7 billion x 17% = $289 million
- Modern Plant Breeding: Total sales in 2012 of $1 billion x 17% = $170 million

Table 6: Economic Impacts of Warehousing and Distribution[2]

	GDP ($ millions)	Labour income ($ millions)	Jobs
Direct			
Pest Control Products	$159	$107	1,866
Modern Plant Breeding	$93	$63	1,098
Sub-Total	$252	$169	2,963
Indirect and Induced			
Pest Control Products	$184	$100	1,839
Modern Plant Breeding	$108	$59	1,082
Sub-Total	$293	$159	2,920
Total Direct, Indirect, and Induced			
Pest Control Products	$343	$207	3,704
Modern Plant Breeding	$202	$122	2,179
Total	$545	$328	5,883

Overall, warehousing and distribution of plant science innovation products results in $545 million in GDP, $328 million in labour income, and over 5,880 jobs.

3.2. Agricultural Production Impacts

The largest and most important economic impacts arise from increased agricultural production of field crops, vegetables, and fruits in Canada. To be meaningful, this impact assessment of plant science innovations is based on the current situation compared to what is referred to as the *counterfactual* case. The counterfactual case requires constructing a scenario "without pest management using plant science products".

[2] Results in Table 6 are based on IO multipliers for the "Miscellaneous Warehousing and Distribution" industry which includes agricultural input warehousing and distribution.

Comparing studies where farmers use or do not use any pest management measures, such as herbicides or insecticides, would actually overstate the benefits of pest management measures. For instance, farmers who did not apply any herbicide may spend more time mechanically controlling weeds with frequent cultivations. These farmers would also likely plough down green manure cover crops and practice more crop rotation and summer fallowing to reduce pests, increase yields and return nitrogen to the soil.

Comparing conventional and organic production of crops provides a more realistic, although imperfect, counterfactual scenario. Organic crop production is more labour intensive because farmers respond to fewer chemical inputs by using more labour and cultivation to control pests and weeds. However, there are a number of reasons that this is an imperfect comparison:

- Organic production is not devoid of pest management measures. In fact, many of CropLife Canada's members produce organic products for pest management.
- Organic production is generally on a much smaller scale than conventional production, so there may be missing economies of scale.
- The quality of some organic crops differs from conventional agriculture. For example, although nutritional value is generally found to be the same (Smith-Spangler et al. 2012), some organic produce can often be less aesthetically pleasing compared to conventional produce.

The difference in yields between the current situation and the counterfactual, by crop and type of technology, were estimated based on 22 studies from academic literature, supplemented with input from experts from the horticulture industry. Since the previous CropLife Canada study "Cultivating a Vibrant Economy", a number of newer studies have emerged comparing organic to conventional production. Of course, not every study compares the same farming system, time period or location. Therefore estimates from each study were weighted according to how closely they may reflect the current situation in Canada's crop production sector. Older studies, studies not for North America and studies that compared only the use/non-use of pest management measures were given lower weight.

Expert input on the yield implications for horticulture crops in Canada was particularly valuable. Numerous minor use pest control products have been approved in recent years under the Pest Management Centre's Minor Use Program. In many cases, these minor use pest control products are essential to preventing the complete loss of some horticulture crops in certain years.[3]

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[3] The Pest Management Centre (PMC), Agriculture and Agri-food Canada, works with other federal departments, provincial governments, industry representatives and producer groups, to match major weed, disease and insect problems in the agricultural regions of Canada with potential pesticide solutions. This collaborative work allows Canadian farmers to access to the same range of pesticide products as farmers in other countries. In particular, growers of horticultural and other specialty crops require a lot of diverse products (insecticides, fungicides and herbicides) for use on relatively small areas of production. Since its inception in 2003, PMC has facilitated access to more than 1,350 new pest control solutions – whether chemical, cultural, biological or mechanical – that are now available to Canadian growers.

Agricultural Production Impacts by Crop

To examine the impacts on agricultural production, the yield impacts discussed above were applied to data for average crop yields, acreage, and prices from 2010/2011 to estimate the impact on the value of field crop, vegetable, potato and fruit production and the associated gains in value resulting from the use of pest control products and modern plant breeding. From these data, production impacts were estimated across 17 field crops, 13 fruits, and 29 vegetables.

Field Crops

Table 7: Impact of Plant Science Innovations on Field Crop Production, by Crop and Technology

	Total Crop Value ($000s)	% of Yield Attributable to Plant Science Innovations	Value Attributable to Plant Science Innovations ($000s)
Barley*	$765,130	21.2%	$162,399
Beans*	$161,427	15.1%	$24,295
Canary seed*	$77,013	12.9%	$9,935
Canola	$7,778,090		
Pest control products		36.5%	$2,341,101
Modern plant breeding		17.7%	$1,368,684
Chick peas*	$37,875	11.2%	$4,255
Corn	$2,393,687		
Pest control products		22.8%	$468,129
Modern plant breeding		14.6%	$344,283
Flaxseed*	$268,593	18.3%	$49,132
Lentils	$730,119		
Pest control products		11.2%	$75,321
Modern plant breeding		10.0%	$59,602
Mustard seed*	$88,276	9.4%	$8,333
Oats*	$520,062	18.0%	$93,624
Peas*	$901,651	20.4%	$184,052
Rye*	$53,270	8.5%	$4,546
Soybeans	$2,407,209		
Pest control products		23.9%	$533,922
Modern plant breeding		8.7%	$177,434
Sugar beets	$32,988		
Pest control products		26.3%	$7,825
Modern plant breeding		10.0%	$3,180
Sunflower	$21,104		
Pest control products		22.4%	$4,626
Modern plant breeding		10.0%	$459
Wheat	$5,863,083		
Pest control products		20.0%	$1,169,322
Modern plant breeding		10.0%	$19,479
Pest Control Sub-total		**23.8%**	**$5,140,816**
Modern Plant Breeding Sub-total		**10.5%**	**$1,973,120**
Field Crop Total	**$22,099,574**	**32.2%**	**$7,113,936**

* Pest control products only used in the production of these crops

Plant science innovations contributed over $7.1 billion to Canada's field crop production. Much of the gains came from substantially higher canola production, which benefited from $3.7 billion in higher production.

Vegetables and Potatoes

Table 8 documents the impact of plant science innovations (pest control products) for vegetable and potato production. Total gains from use of the technology amount to over $435 million for vegetables, and a similar amount ($434 million) for potatoes. As noted earlier, pest control products play a crucial role in protecting potatoes and many vegetable and fruit crops from potential catastrophic losses.

Table 8: Impact of Pest Control Products on Vegetable and Potato Production, by Crop

	Total Crop Value ($000s)	% of Yield Attributable to Plant Science Innovations	Value Attributable to Plant Science Innovations ($000s)
Asparagus	$24,869	45.4%	$11,279
Beans	$30,752	37.7%	$11,602
Beets	$14,083	45.0%	$6,334
Broccoli	$44,090	54.6%	$24,087
Brussels sprouts	$6,258	66.8%	$4,181
Cabbage	$64,637	57.5%	$37,165
Carrots	$90,429	51.4%	$46,474
Cauliflower	$24,676	64.2%	$15,843
Celery	$15,116	52.5%	$7,940
Corn	$71,770	45.4%	$32,565
Cucumbers	$26,897	58.5%	$15,747
Dry onions	$63,795	55.0%	$35,090
Garlic	$9,255	41.9%	$3,876
Leeks	$7,500	48.0%	$3,597
Lettuce	$56,446	59.8%	$33,771
Other melons	$8,957	61.1%	$5,473
Parsley	$3,743	13.1%	$490
Parsnips	$6,524	66.8%	$4,359
Peas	$23,141	58.2%	$13,478
Peppers	$38,558	66.8%	$25,762
Pumpkins	$17,805	59.9%	$10,661
Radishes	$10,682	61.1%	$6,526
Rhubarb	$2,165	34.8%	$754
Rutabagas and turnips	$21,051	53.3%	$11,220
Shallots	$16,043	55.4%	$8,885
Spinach	$8,054	55.4%	$4,461
Squash and zucchinis	$25,698	53.2%	$13,668

	Total Crop Value ($000s)	% of Yield Attributable to Plant Science Innovations	Value Attributable to Plant Science Innovations ($000s)
Tomatoes	$72,465	49.6%	$35,929
Watermelon	$7,432	55.4%	$4,116
Vegetable Total	**$812,882**	**49.3%**	**$435,333**
Potatoes	**$1,103,407**	**39.3%**	**$433,891**

Fruits

For fruit production, pest control products account for over $353 million in value of the crops. Much of the value attributable to plant science innovations comes from higher apple and grape production in Canada.

Table 9: Impact of Pest Control Products on Fruit Production, by Crop

	Total Crop Value ($000s)	% of Yield Attributable to Plant Science Innovations	Value Attributable to Plant Science Innovations ($000s)
Apples*	$188,810	49.4%	$93,303
Apricots	$757	63.3%	$479
Blueberries	$215,527	27.8%	$59,996
Cherries sour	$4,583	50.0%	$2,290
Cherries sweet	$42,610	50.0%	$21,291
Cranberries	$101,321	32.8%	$33,267
Grapes	$147,141	54.8%	$80,657
Nectarines	$4,723	49.1%	$2,320
Peaches	$34,656	40.5%	$14,036
Pears	$7,013	32.7%	$2,292
Plums and prunes	$5,511	63.3%	$3,488
Raspberries	$24,005	26.7%	$6,409
Strawberries	$70,221	48.0%	$33,721
Fruit Total	**$846,876**	**43.3%**	**$353,548**

* With the recent approval of Arctic apples, future year impacts for this crop will include a modern plant breeding dimension

Summary of Agricultural Production Impacts

Table 10 summarizes the overall impacts of plant science innovations on agricultural production in Canada. The value to agricultural production is almost $8.3 billion, with crop protection products accounting for about $6.4 billion and modern plant breeding accounting for $1.97 billion.

Table 10: Summary of Agricultural Production Impacts by Crop and Technology

	Total Crop Value ($000s)	% of Yield Attributable to Plant Science Innovations	Value Attributable to Plant Science Innovations ($000s)
Field Crops	$22,099,574	32.2%	$7,113,936
Fruits	$846,876	43.3%	$353,548
Vegetables	$812,882	49.3%	$435,333
Potatoes	$1,103,407	39.3%	$433,891
Total	**$24,862,738**	**32.6%**	**$8,336,707**
Pest Control Share of Total		24.5%	$6,363,587
Modern Plant Breeding Share of Total		8.7%	$1,973,120

Agricultural Production Impacts by Province

Table 11: Agricultural Production Impacts from Plant Science Innovations, by Province ($000s)

	Crops	Fruit	Vegetables	Potatoes	Provincial Total
Newfoundland and Labrador	$0	$279	$2,106	$745	**$3,131**
Prince Edward Island	$11,153	$2,731	$4,087	$106,654	**$124,624**
Nova Scotia	$5,503	$21,665	$10,503	$2,098	**$39,768**
New Brunswick	$6,753	$11,913	$3,028	$53,071	**$74,765**
Quebec	$400,044	$76,840	$158,627	$54,814	**$690,325**
Ontario	$1,083,918	$111,067	$192,234	$38,081	**$1,425,300**
Manitoba	$861,536	$61	$4,506	$74,038	**$940,141**
Saskatchewan	$2,795,925	$0	$759	$14,142	**$2,810,827**
Alberta	$1,928,674	$532	$9,758	$74,069	**$2,013,034**
British Columbia	$23,242	$126,937	$31,355	$16,178	**$197,712**
Canada Total*	**$7,113,936**	**$353,548**	**$435,333**	**$433,891**	**$8,336,707**

*Note: There are slight margins of error between the Canada totals and the provincial sums as a result of missing data for various crops at the provincial level.

Most of the impacts on agricultural production are concentrated in the Prairies, especially in Saskatchewan and Alberta. In Saskatchewan alone, plant science innovations resulted in more than $2.8 billion in additional agricultural output.

Economic Impacts

In order to estimate the economic impacts of gains in agricultural production due to plant science innovations, RIAS Inc. worked with Statistics Canada to develop a customized run of their Input-Output (IO) simulation model. RIAS Inc. adjusted a number of parameters in the IO model's underlying production functions to more accurately reflect the input and technological differences in agricultural systems between conventional and organic agricultural practices.

Table 12 shows the total direct, indirect and induced impacts of the gains to agricultural production on the economy, by province. Overall, the use of plant science innovations generated a total of almost $7.7 billion of Canada's GDP, $3.66 billion in labour income and 111,770 jobs. Just under $4.0 billion of GDP is a result from higher production on Canada's farms. Another $3.7 billion in GDP is from increases in output from suppliers to Canada's farms. The economic impacts were largely concentrated in Saskatchewan, Alberta, and Ontario.

Table 12: Direct, Indirect and Induced Economic Impacts of Plant Science Innovations, by Province

	GDP ($ 000s)	Labour Income ($ 000s)	Jobs (FTEs)
Newfoundland and Labrador	$19,495	$6,260	134
PEI	$81,670	$37,920	1,221
Nova Scotia	$46,120	$24,345	993
New Brunswick	$67,375	$31,400	1,067
Quebec	$612,530	$318,950	10,204
Ontario	$1,431,895	$776,760	17,612
Manitoba	$696,800	$337,220	13,447
Saskatchewan	$2,379,040	$959,935	41,891
Alberta	$1,979,040	$953,700	19,545
B.C.	$408,970	$207,570	5,639
Yukon	$460	$260	5
Northwest Territories	$1,400	$750	10
Nunavut	$920	$380	4
Canada Total*	**$7,725,900**	**$3,655,500**	**111,774**

*Note: There are slight margins of error between the Canada totals and the provincial sums as a result of missing data for various crops at the provincial level.

Table 13 shows that pest control products largely drove the economic benefits and agricultural yield improvements in Canada. In total, it is estimated that pest control products supported $5.9 billion in GDP, $2.8 billion in labour income and 85,300 jobs.

Table 13: Direct, Indirect and Induced Economic Impacts of Pest Control Products, by Province

	GDP ($ 000s)	Labour Income ($ 000s)	Jobs (FTEs)
Newfoundland and Labrador	$19,500	$6,260	134
PEI	$80,470	$37,360	1,203
Nova Scotia	$43,910	$23,180	945
New Brunswick	$65,640	$30,595	1,040
Quebec	$489,750	$255,020	8,159
Ontario	$1,085,775	$589,000	13,355
Manitoba	$527,835	$255,450	10,186
Saskatchewan	$1,753,575	$707,560	30,878
Alberta	$1,475,115	$710,855	14,568
B.C.	$397,125	$201,560	5,475

	GDP ($ 000s)	Labour Income ($ 000s)	Jobs (FTEs)
Canada Total*	**$5,897,340**	**$2,790,330**	**85,319**

*Note: There are slight margins of error between the Canada totals and the provincial sums as a result of missing data for various crops at the provincial level.

Table 14 shows the economic impacts of modern plant breeding by province. Canada's farmers are increasingly using seeds derived from modern plant breeding technology. It is likely that the share of the economic benefit from this technology will continue to grow over time as more farmers adopt the seeds and plant science companies continue to develop new, beneficial plant traits.

Table 14: Direct, Indirect and Induced Economic Impacts of Modern Plant Breeding, by Province

	GDP ($ 000s)	Labour Income ($ 000s)	Jobs (FTEs)
Newfoundland and Labrador	$0	$0	0
PEI	$1,198	$556	18
Nova Scotia	$2,208	$1,166	48
New Brunswick	$1,732	$807	27
Quebec	$122,778	$63,932	2,045
Ontario	$346,118	$187,759	4,257
Manitoba	$168,968	$81,773	3,261
Saskatchewan	$625,466	$252,373	11,014
Alberta	$503,928	$242,842	4,977
B.C.	$11,847	$6,013	163
Canada Total*	**$1,828,553**	**$865,181**	**26,454**

*Note: There are slight margins of error between the Canada totals and the provincial sums as a result of missing data for various crops at the provincial level.

Contribution to Canada's Agricultural Trade Balance

With vast expanses of land and a relatively small population, Canada produces a large surplus of agricultural products. Canada is among the world's top 10 exporters of agricultural products with annual exports of field crops, vegetables, fruits and potatoes exceeding $23 billion in 2014. Over the past 5 years, exports of these agricultural products have increased by 45% in real terms.

Table 15: Exports of Agricultural Products by HS Code, 2010 to 2014 ($ millions)

	2010	2011	2012	2013	2014
Cereals	5,741	6,977	7,516	8,312	9,682
Oil seeds, industrial and medicinal plants	5,618	6,770	8,380	7,534	8,452
Vegetables, Potatoes and Other Tubers	3,464	3,632	3,166	4,402	4,919
Fruits and Nuts	410	532	629	592	650
Total	15,234	17,911	19,691	20,840	23,702

Source: Industry Canada, Trade Data Online

A large portion of Canada's net trade balance results from the use of plant science innovations. Unsurprisingly, Canada's wheat and oil seed crops – especially canola – that demonstrate the greatest benefit from plant science innovations are also the biggest contributors to Canada's exports. In 2012/13 oil seeds and grains together make up nearly $16 billion of Canada's $20.3 billion in field crops, vegetables, fruits, and potatoes exports.

In 2012/13 Canada's net crop trade balance was $11.6 billion. Plant science innovations add an estimated $8.3 billion dollars to Canada's crop production, or 71% of the value of Canada's trade balance in crops.

Table 16: Net Impact of Plant Science Innovations on Canada's Agricultural Trade Balance, 2012/13

	Average of 2012 and 2013
Exports of field crops, vegetables, and fruits	$20.3 billion
Imports of field crops, vegetables, and fruits	$8.7 billion
Trade balance of field crops, vegetables, and fruits	$11.6 billion
Contribution of plant science innovations to Canada's agricultural trade balance	$8.3 billion
Proportion of crop trade balance attributable to plant science innovations	**71%**
Pest control product imports (HS3808)	-$1.4 billion
Modern plant breeding imports*	-$0.09 billion
Net effect of plant science innovations on Canada's trade balance	$6.8 billion

* Estimate, based on GMC (2012) findings that 18.2% of commercial seeds are imported to Canada

After accounting for the value of imported pest control products and seeds from modern plant breeding (estimated to total $1.5 billion), the impact of plant science innovations to Canada's net trade balance is $6.8 billion per year.

Food Processing Economic Impacts

The additional agricultural output attributable to use of plant science innovations generates additional value in Canada's food processing sector. Historically, Canada's bakery industries and the oilseed and grain milling industries have expanded and shrank with Canada's agricultural production. The same has not been true for the fruit and vegetable preparations industry. Even when accounting for demand factors such as the value of the Canadian dollar and the size of the Canadian and U.S. economies - the U.S. is naturally the main export destination for much of Canada's production - for every one dollar increase in crop production, the oil seed and grain milling and bakery industries expand output by 36 cents.

When capturing the indirect and induced economic effects in the Statistics Canada IO model, the indirect effects of additional agricultural production as an input must be removed. For each dollar of food manufacturing output, 46 cents, according to the AAFC report "An Overview of the Canadian Agriculture and Agri-Food System", is for agricultural products.

In total, the additional agricultural production generates a significant $1.8 billion in GDP for Canada's food processing sector. In total, the boost to food processing generates $910 million in labour income and an additional 16,930 jobs.

Table 17: Economic Impacts of Food Processing from Plant Science Innovations Industry

	GDP ($ millions)	Labour income ($ millions)	Jobs
Direct			
Pest control products	$528	$248	4,513
Modern plant breeding	$186	$88	1,594
Sub-Total	**$714**	**$336**	**6,106**
Indirect and Induced			
Pest control products	$793	$424	7,998
Modern plant breeding	$280	$150	2,825
Sub-Total	**$1,073**	**$574**	**10,822**
Direct, Indirect, and Induced			
Pest control products	$1,321	$672	12,510
Modern plant breeding	$466	$237	4,418
Total	**$1,787**	**$910**	**16,929**

Note: Net of economic impacts related to crop production.

3.3. Summary of the Economic Impacts of Plant Science Innovation Products

Table 18 provides an overall summary of economic impacts of plant science innovations throughout the value-chain.

In total, the plant science innovation sector has an economic footprint of about $9.8 billion of GDP in Canada's economy. These economic impacts include supply chain impacts – production and supply for seeds with novel traits and for crop protection products – impacts on agricultural production in Canada, and finally forward-linkage impacts in Canada's food processing industry.

The $9.8 billion in GDP supports over 131,000 jobs in Canada and $4.7 billion in income for Canadians.

Table 18: Economic Impacts throughout the Value-Chain of the Plant Science Innovations Industry

	GDP ($ millions)	Labour income ($ millions)	Jobs
Production for Domestic Use and Export			
Pest control products	$669	$274	4,344
Modern plant breeding	$494	$193	4,676
Sub-Total	**$1,163**	**$467**	**9,020**
Research and Development			
Pest control products	$159	$107	1,866
Modern plant breeding	$93	$63	1,098
Sub-Total	**$252**	**$169**	**2,963**
Wholesale and Distribution			

	GDP ($ millions)	Labour income ($ millions)	Jobs
Pest control products	$343	$207	3,704
Modern plant breeding	$202	$122	2,179
Sub-Total	**$545**	**$328**	**5,883**
Agricultural Production			
Pest control products	$4,885	$2,310	77,271
Modern plant breeding	$1,133	$550	19,599
Sub-Total	**$6,018**	**$2,860**	**96,870**
Food Processing Sector			
Pest control products	$1,321	$672	12,510
Modern plant breeding	$466	$237	4,418
Sub-Total	**$1,787**	**$910**	**16,929**
Total			
Pest control products	$7,377	$3,569	99,695
Modern plant breeding	$2,388	$1,165	31,970
Grand Total	**$9,765**	**$4,735**	**131,666**

Note: Agricultural production is shown net of wholesaling, distribution and production impact of plant science innovations.

3.4. Tax Revenues

The Statistics Canada IO model estimates the amount of indirect taxes collected as a result of a change in output. In addition, we have extended the model to estimate provincial and federal collections of income, payroll and corporate taxes as per the equations provided in Appendix 3 - Measuring Economic Impacts.

Table 19: Estimates of Indirect Tax Collections by Province and Level of Government, $ 000s

	Federal Indirect Taxes	Provincial Indirect Taxes	Municipal Indirect Taxes	Total
Newfoundland and Labrador	$210	$561	$267	$1,038
PEI	$575	$4,977	$1,296	$6,849
Nova Scotia	$625	$1,630	$2,210	$4,465
New Brunswick	$630	$3,040	$1,895	$5,565
Quebec	$5,870	$26,975	$23,050	$55,895
Ontario	$14,545	$47,825	$70,445	$132,815
Manitoba	$4,435	$28,340	$24,990	$57,765
Saskatchewan	$11,970	$79,650	$85,150	$176,770
Alberta	$16,585	$47,950	$68,575	$133,110
B.C.	$5,415	$18,230	$11,965	$35,615
Yukon	$9	$10	$9	$28
Northwest Territories	$26	$50	$35	$110
Nunavut	$12	$7	$6	$25
Total	$60,910	$259,245	$289,895	$610,050

Based on the Statistics Canada IO model, indirect tax collections, including taxes such as HST, fuel taxes, and other excise taxes, earned an additional $610 million for government coffers. The provinces and municipalities were the primary beneficiaries of higher indirect taxes from higher agricultural output, particularly governments in Saskatchewan, Alberta and Ontario.

Table 20 indicates that income tax collections would be $900 million lower without the use of plant innovation products in Canada's agricultural industry.

Table 20: Income and Payroll Tax Collections by Province and Level of Government, $ 000s

	Provincial	Federal	Total
Newfoundland and Labrador	$600	$985	$1,585
PEI	$3,700	$5,955	$9,655
Nova Scotia	$2,515	$3,825	$6,335
New Brunswick	$2,620	$4,930	$7,555
Quebec	$54,360	$50,095	$104,450
Ontario	$74,050	$122,000	$196,050
Manitoba	$36,895	$52,965	$89,860
Saskatchewan	$76,400	$150,770	$227,170
Alberta	$62,610	$149,790	$212,400
B.C.	$15,675	$32,600	$48,280
Yukon	$13	$41	$54
Northwest Territories	$47	$118	$165
Nunavut	$19	$60	$78
Total	$329,510	$574,130	$903,640

Table 21 shows that corporate tax collections would also likely drop $284 million in the absence of plant science innovations.

Table 21: Corporate Tax Collections by Province and Level of Government, $ 000s

	Provincial	Federal	Total
Newfoundland and Labrador	$235	$300	$530
PEI	$635	$1,740	$2,370
Nova Scotia	$585	$965	$1,550
New Brunswick	$530	$1,400	$1,930
Quebec	$10,170	$12,960	$23,130
Ontario	$16,270	$29,730	$46,000
Manitoba	$5,800	$13,985	$19,785
Saskatchewan	$50,400	$49,140	$99,545
Alberta	$32,985	$42,830	$75,815
B.C.	$5,200	$8,040	$13,240
Yukon	$2	$8	$10
Northwest Territories	$16	$30	$45
Nunavut	$3	$14	$17

	Provincial	Federal	Total
Total	$122,830	$161,140	$283,970

In sum, Table 22 shows that total tax collections related to the additional agricultural production from plant science innovations are $1.8 billion, and are significant across each level of government.

Table 22: All Tax Collections by Province and Level of Government, $ 000s

	Local	Provincial	Federal	Total
Newfoundland and Labrador	$265	$1,394	$1,490	$3,150
PEI	$1,295	$9,310	$8,270	$18,875
Nova Scotia	$2,210	$4,730	$5,410	$12,350
New Brunswick	$1,895	$6,190	$6,965	$15,050
Quebec	$23,050	$91,505	$68,925	$183,475
Ontario	$70,445	$138,145	$166,275	$374,865
Manitoba	$24,990	$71,035	$71,385	$167,415
Saskatchewan	$85,150	$206,450	$211,885	$503,480
Alberta	$68,575	$143,550	$209,205	$421,330
B.C.	$11,965	$39,105	$46,055	$97,130
Yukon	$9	$25	$58	$92
Northwest Territories	$35	$114	$175	$322
Nunavut	$6	$29	$85	$119
Total	$289,895	$711,580	$796,180	$1,797,660

3.5. Economic Impacts in Other Sectors

Non-Agricultural and Domestic Use

These uses include industrial vegetation management, turfgrass farms, lawns and landscaping around homes and institutions, municipal parks, golf courses and sports fields. Although a multi-billion dollar sector in Canada, reliable statistics for this sector are scarce.

The industrial vegetation management sector carries out the control, removal or alteration of vegetation to achieve the objectives of land users. The main users of vegetation management services are utilities, such as electrical distribution and pipeline companies, railways, highway maintenance agencies and those charged with fighting invasive/noxious vegetation. This last point is a relatively recent one. The World Conservation Union identified invasive alien species as the second most significant threat to biodiversity, after habitat loss.

Securing infrastructure

A growing concern is assuring the security of utilities infrastructure, and how this security can be jeopardized through improperly maintained rights-of-way. The vegetation management sector in Canada does about $50 million in business a year, about $20 million of that being for herbicides and $30 million for the cost of applying the herbicides and the other vegetation management methods, such as hand trimming, mowing, etc.

RIAS Inc. (2006) found that withdrawal of phenoxy herbicides would have two immediate effects and a more important follow-on effect. The immediate effects would be an increase in the costs of industrial vegetation management estimated to be 150% (i.e., from about $7.0 million to about $17.5 million) along with a decrease in the effectiveness of weed control and brush management.

The follow-on effect would be an increase in the events that industrial vegetation management is intended to prevent (i.e., power outages through brush contact with transmission lines, the inability to access facilities quickly for maintenance or in response to an emergency/failure, reduced visibility at crossroads[4] and the loss of even more land to invasive species). Ensuring utilities infrastructure security is also an ongoing concern.

Regarding other uses of pest control products, RIAS Inc. (2006) examined the benefits of phenoxy herbicides for residential lawns/landscaping and golf courses. This work cited a study by the Université Laval that demonstrated a mean price premium of 7.7% across all landscape attributes and all values of houses from well-kept lawns, and found that on a net present value basis, the cost of maintaining consistently high turf quality is about 60 times higher if herbicides were not used.

For golf courses, the study found that removal of access to phenoxy herbicides alone would increase treatment costs at golf courses in Canada from about $3 million to about $26 million, but without maintaining course quality. The decline in quality could cost Canadian courses both their regular customers and the high-profile competitions that bring additional economic benefits to local communities.

[4] For example, Transport Canada's Grade Crossing Regulations (SOR/2014-275) recognizes the risks posed by brush that obstruct sightlines at railway crossings, and establishes clear responsibilities for road authorities and railway companies to manage and mitigate those risks. (see http://gazette.gc.ca/rp-pr/p2/2014/2014-12-17/html/sor-dors275-eng.php)

4. Environmental Impacts

According to the United Nations Food and Agriculture Organization (FAO), land suitable for agriculture is currently 4.9 billion hectares, of which 1.5 billion hectares is currently used for crop production. When pest management measures were first introduced, yields improved and greatly reduced land-use relative to production. In recent decades, advancements in plant science innovation have led to a conversion in products used in crop production (increased use of newer products with lower toxicity/environmental impact) and have increased integrated pest management and no-till/conservation-till practices, leading to even greater yield gains.

Conserving biodiversity, improving soil quality and reducing gland use

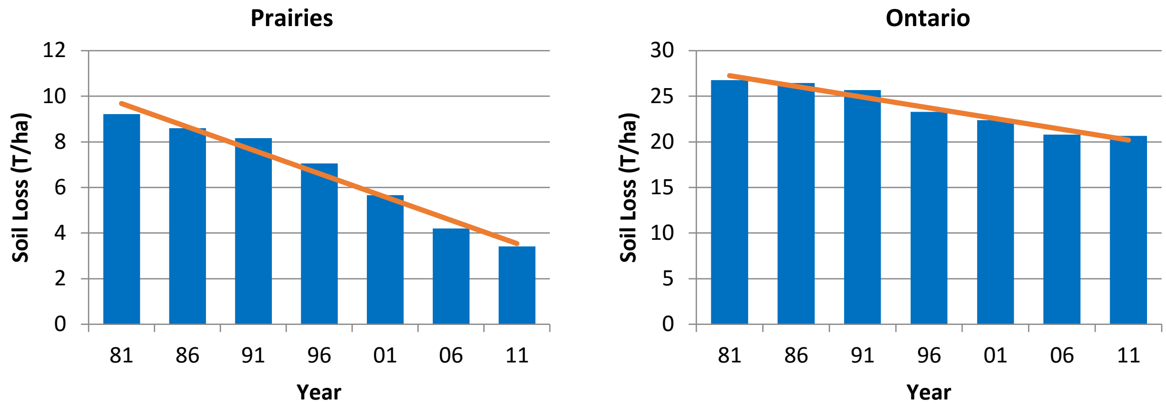
Factors threatening biodiversity include the expansion of human habitat, the reduction of wildlife habitats, as well as the negative impact of invasive species, such as weeds and fungi. Pest control products contribute to biodiversity conservation by enhancing agricultural productivity and controlling invasive species:

- By increasing crop yields and minimizing losses caused by pests and diseases, pest control products help to increase production on existing land and limit encroachment on non-agricultural land, thereby helping to preserve wildlife habitats, such as forest, wetlands and grasslands.
- Invasive plant species such as weeds and fungi can also have a negative impact on wildlife habitats. Pest control products help control these species and protect wildlife.
- Herbicides help to enable the spread of conservation tillage, which helps improve soil quality and reduce erosion. In turn, this helps to improve habitats and limit agricultural encroachment.

Carpenter (2011) detailed review of the scientific literature on biodiversity found that the impacts of biotech crops on biodiversity are positive. By increasing yields, providing additional protection from pest damage, increasing the use of more environmentally friendly herbicides and facilitating the adoption of conservation tillage, biotech crops have already contributed to increasing agricultural sustainability. Modern plant breading technologies such as drought tolerance and salinity tolerance are expected to further alleviate the pressure to convert high biodiversity areas into agricultural use by enabling crop production on suboptimal soils. Nitrogen use efficiency technology is also under development, which can reduce run-off of nitrogen fertilizer into surface waters. The technology promises to decrease the use of fertilizers while maintaining yields or increasing yields achievable with reduced fertilizer rates.

Recent studies for the Canadian Field Print Initiative have also shown that improved agricultural practices have had a significant impact on reducing soil erosion and improving soil quality. Across a range of crops in both the Prairies and Ontario, soil erosion improved over the study period from 1981 to 2011 (Serecon Inc, 2015), with substantial improvements in the risk of soil loss both in Ontario and on the Prairies, as shown in Figure 1. Adoption of reduced tillage practices (62% decrease in conventional till from 1991 to 2006 on the Prairies, 39% reduction in Ontario) has been a strong positive driver in both regions.

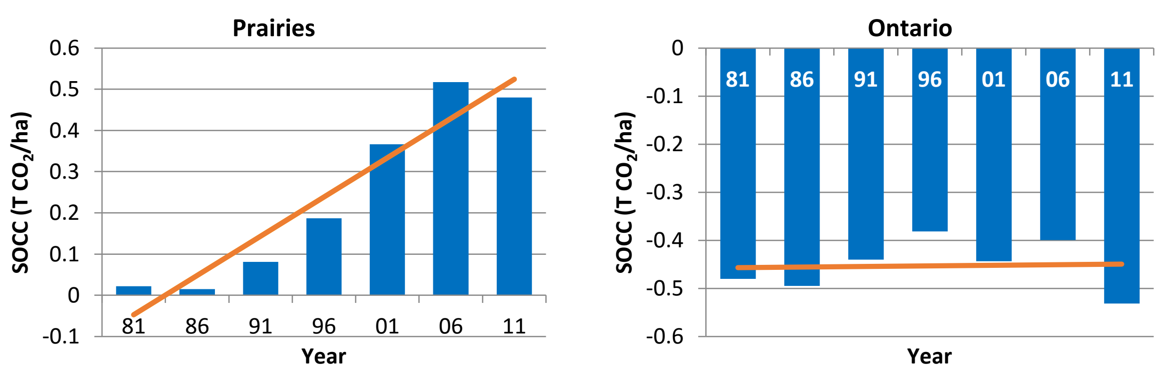
Figure 1: Improvements in Soil Loss - Prairies and Ontario



Source: Serecon Inc, 2015

Figure 2 shows a significant increase in the rate of carbon sequestration by prairie cropland soils between 1981 and 2011, as measured by soil organic carbon change (SOCC). The increase in organic soil carbon on the Prairies resulted primarily from reduced tillage and summerfallow. Organic soil carbon has remained relatively constant for Ontario cropland, as areas of hay and pasture have been converted to annual crops over the time period. The negative impact of this land use change on Ontario's soil carbon levels has been partially offset by adoption of conservation tillage practices, enabled through plant science innovations.

Figure 2: Soil Organic Carbon Change - Prairies and Ontario



Source: Serecon Inc, 2015

Globally, Brookes and Barfoot (2014) found that plant science innovations represent land-saving technologies that have significantly increased productivity on the current 1.5 billion hectares of land used in crop production, thereby helping prevent deforestation and protect biodiversity in forests and in other in-situ biodiversity sanctuaries. If the 328 million tonnes of additional food, feed and fibre produced by biotech crops during the period 1996 to 2011 had not been produced, an additional 108.7 million hectares would have been required to produce the same quantity of food. This would have required fragile marginal lands, less suitable for crop production, to be ploughed, and forests rich in biodiversity to be felled for slash and burn agriculture in developing countries, thereby diminishing biodiversity worldwide.

Reducing agriculture's environmental footprint

Plant science innovations have helped reduce the environmental footprint of agriculture. Progress to-date includes: increased conservation of fossil-based fuels (such as diesel) that were traditionally required for more intensive cultivation and/or multiple applications of pesticides; decreasing CO_2 emissions through no/ less ploughing; and conserving soil and moisture by optimizing the practice of no till through application of modern plant science technologies and adherence to IPM strategies.

Increasing the efficiency of water usage will have a major impact on conservation and availability of water globally. Some sources estimate that as much as 70% of fresh water is currently used by agriculture globally, and there are growing concerns that this is not sustainable in the future as traditional glacial, snowpack and ground water reserves diminish and as global population increases by almost 30% to over 9 billion by 2050.[5] The first biotech corn hybrids from modern plant breeding with a degree of drought tolerance were approved in the U.S. and Canada in 2011 and in sub-Saharan African countries in 2013.[6] Drought tolerance is expected to improve the sustainability of cropping systems, especially in regions where drought has been more prevalent and prolonged with severe social, economic and environmental impacts.

Helping mitigate climate change and reducing greenhouse gases

Plant science innovations contribute to a reduction of greenhouse gases and help mitigate climate change in two principal ways. First, plant science innovations lead to permanent savings in carbon dioxide (CO_2) emissions through reduced use of fossil-based fuels, mainly associated with reduced tillage. Second, plant science innovations have led to greater soil carbon sequestration from conservation tillage. Globally, these two effects were estimated to result in a saving of 23 billion kg of CO_2, or the equivalent of removing 10.2 million cars from the road in 2011 (Brookes and Barfoot, 2014).

Droughts, floods, and temperature changes are predicted to become more prevalent and more severe as we face the new challenges associated with climate change. There will be a need for

[5] This popular "70% of fresh water" estimate should be viewed with caution. Many studies used to establish this estimate count rainfall as part of the water needs but don't count the transpiration of water from agricultural plants back to the atmosphere.

[6] USDA and CFIA approved Monsanto's MON 87460 drought resistant corn in 2011. Tanzania Official Seed Certification Institute (TOSCI) approved three drought-tolerant maize hybrids: WE2109, WE2112, and WE2113, in December 2013.

faster crop improvement programs to develop varieties and hybrids that are well adapted to more rapid changes in climatic conditions. Several modern plant breeding tools, including tissue culture, diagnostics, genomics, molecular marker-assisted selection (MAS), RNAi and biotech GE crops are being used collectively to speed the process for developing new adapted varieties of crops to help mitigate the impact of climate change on crop production. The combination of pest control products and modern plant breeding has allowed farmers to reduce tillage on a significant portion of cropped land, resulting in less CO_2 emissions, conservation of soil and moisture, and greater sequestration of CO_2 in cropland soils.

4.1. Contribution of Plant Science Innovations to Land Use Changes

Plant science innovations have allowed a large swath of Canada's land to remain uncultivated. The literature on crop yield impacts allows one to measure the impact of these technologies on land-use by estimating how much more land would be required to obtain the same level of crop production output. The formula for a given crop, fruit, or vegetable *i* is given in Equation 1 below.

Equation 1: Calculation of Land Use Reductions

$$\boldsymbol{Area\ of\ land\ saved_i = Current\ Area\ Under\ Production_i - \frac{Current\ Area\ Under\ Production_i}{1 - \%\ Yield\ attributable\ to\ plant\ science\ innovations_i}}$$

Tables 23 through 27 below show the detailed estimates of land-use reductions due to the use of plant science innovations in Canada.

Table 23: Estimated Reductions in Land-Use for Production of Field Crops Due to Pest Control Products, by Crop

	Current Area (hectares)	% of Yield Attributable to Plant Science Innovations	Additional area required to attain the same level of output without use of plant science innovations (hectares)
Barley	2,931,400	21.2%	789,831
Beans	104,150	15.1%	18,452
Canary seed	110,300	12.9%	16,336
Canola	8,490,750	38.7%	5,929,360
Chick peas	76,850	11.2%	9,725
Corn	1,737,100	22.8%	600,652
Flaxseed	410,700	18.3%	91,945
Lentils	1,039,000	11.2%	143,172
Mustard seed	141,650	9.4%	14,766
Oats	1,224,450	18.0%	268,828
Peas dry	1,427,350	20.4%	366,092
Rye all	124,450	8.5%	11,610
Soybean	1,774,800	23.9%	603,242

	Current Area (hectares)	% of Yield Attributable to Plant Science Innovations	Additional area required to attain the same level of output without use of plant science innovations (hectares)
Sugar beets	9,500	26.3%	3,742
Sunflower	34,400	22.4%	10,155
Wheat	10,127,950	20.0%	2,542,062
Total	**29,764,800**	**25.3%**	**11,419,970**

Table 24: Estimated Reductions in Land-Use for Production of Field Crops Due to Modern Plant Breeding, by Crop

	Current Area (hectares)	% of Yield Attributable to Plant Science Innovations	Additional area required to attain the same level of output without use of plant science innovations (hectares)
Canola	8,405,843	17.7%	1,813,140
Corn	1,702,358	14.6%	291,819
Lentils	831,200	10.0%	92,356
Soybeans	1,473,084	8.7%	141,229
Sugar beets	9,120	10.0%	1,013
Sunflower	6,880	10.0%	764
Wheat	303,839	10.0%	33,760
Total	**12,732,324**	**15.6%**	**2,374,082**

Table 25: Estimated Reductions in Land-Use for Vegetable Production, by Crop

	Current Area (hectares)	% of Yield Attributable to Plant Science Innovations	Additional area required to attain the same level of output without use of plant science innovations (hectares)
Asparagus	1,834	45.4%	1,522
Beans	8,907	37.7%	5,396
Beets	1,415	45.0%	1,156
Broccoli	4,141	54.6%	4,987
Brussels sprouts	538	66.8%	1,083
Cabbage	5,746	57.5%	7,773
Carrots	8,397	51.4%	8,878
Cauliflower	1,692	64.2%	3,034
Celery	743	52.5%	822
Corn	21,349	45.4%	17,733
Cucumbers	1,924	58.5%	2,716
Dry onions	5,077	55.0%	6,206
Garlic	329	41.9%	237
Leeks	320	48.0%	295
Lettuce	3,712	59.8%	5,528

	Current Area (hectares)	% of Yield Attributable to Plant Science Innovations	Additional area required to attain the same level of output without use of plant science innovations (hectares)
Other melons	590	61.1%	926
Parsley	192	13.1%	29
Parsnips	384	66.8%	772
Peas	13,481	58.2%	18,803
Peppers	1,941	66.8%	3,907
Pumpkins	2,799	59.9%	4,177
Radishes	945	61.1%	1,484
Rhubarb	157	34.8%	84
Rutabagas and turnips	1,800	53.3%	2,054
Shallots	710	55.4%	881
Spinach	801	55.4%	994
Squash and zucchinis	2,711	53.2%	3,080
Tomatoes	6,679	49.6%	6,568
Watermelon	671	55.4%	833
Vegetable Total	**99,977**	**51.7%**	**111,958**
Potatoes	**366,827**	**39.3%**	**237,728**

Table 26: Estimated Reductions in Land-Use for Fruit Production, by Crop

	Current Area (hectares)	% of Yield Attributable to Plant Science Innovations	Additional area required to attain the same level of output without use of plant science innovations (hectares)
Apples	17,051	49.4%	16,657
Apricots	98	63.3%	169
Blueberries	73,051	27.8%	28,179
Cherries sour	1,054	50.0%	1,053
Cherries sweet	1,704	50.0%	1,702
Cranberries	6,718	32.8%	3,284
Grapes	12,319	54.8%	14,945
Nectarines	353	49.1%	341
Peaches	2,625	40.5%	1,786
Pears	727	32.7%	353
Plums and prunes	463	63.3%	799
Raspberries	2,368	26.7%	863
Strawberries	3,879	48.0%	3,584
Fruit Total	**122,409**	**35.4%**	**73,714**

Table 27: Summary of Estimated Reductions in Land-Use Due to Plant Science Innovations

	Current Area (hectares)	% of Yield Attributable to Plant Science Innovations	Additional area required to attain the same level of output without use of plant science innovations (hectares)
Field Crops	29,764,800	25.3%	11,419,970
Fruits	122,409	35.4%	73,714
Vegetables	99,977	51.7%	111,958
Potatoes	366,827	39.3%	237,728
Pest control products sub-total	**30,354,013**	25.6%	**11,843,370**
Modern plant breeding sub-total	**12,732,324**	15.6%	**2,374,082**
Grand Total			**14,217,452**

Without plant science innovations, it is estimated that Canada's agriculture area would need to be 50% larger, or about 14.2 million hectares greater to produce the same level of crop production output.

The vast majority of the land-use savings is because of the very high benefits of plant science innovations used for field crops such as canola, wheat, soybeans and corn. For example, without these technologies, canola production in Canada would require 91% more land area to produce the same level of output. Since the late 1990s alone, modern plant breeding has already reduced land-use by over 2.37 million hectares, based on Canada's current crop production.

Pest control products are also very important for wheat production. Without pest management products, wheat production in Canada would require an additional 2.5 million hectares. Wheat was one of the first crops to greatly benefit from pest management products in Canada. The introduction of 2,4-D in the late 1940s provided unprecedented weed control that increased wheat production especially in the arid and semi-arid regions of the Prairies.

Greenhouse Gas Emissions

The 14.2 million hectares of land that is not cultivated due to plant science innovations has varying rates of emission savings due to the alternate use of the land, some of these uses can only be estimated. The total agricultural land in Canada has been quite stable for several decades; the only major change has been an increase in cropped area and a decrease in summer fallow.

There has only been very small areas of expansion of agricultural land into forest and pasture areas. However, when this expansion does happen there is a loss of sequestered carbon from the system and an increase in GHG emissions. Converting forestland and grass land to cropland results in a release of carbon to the atmosphere. The quantity of forest land vs. grassland converted is difficult to predict and the carbon losses of the converted land will depend on where the conversion takes place. Forests in the Boreal Plains have less carbon stored in them than forests in the Pacific Maritime eco-region. The average carbon loss per hectare in the 2014

National Inventory Report is 9.63 t C/ha or 35 t CO_2/ha. Grassland converted to cropland loses only 3.26 t C/ha or 12 t CO_2/ha. Almost 99% of the expanded cropland has come from forest area according to the 2014 National Inventory Report.

Canada does have about 5 million hectares of cropland that has been seeded for temporary use as pasture. A significant portion of this land would be used for crop production if the productivity of all cropland was lower due to a lack of plant science innovation.

Assuming that the additional forest land is available with the proper soil and climatic conditions, the potential GHG emissions avoided by plant science innovation is 35t/ha x 10 million hectares, or 350 million tonnes of CO_2, about half of Canada's annual emissions from all sources. We assume that these land clearing impacts would occur over a 20 year time period, which is consistent with the approach used in the development of the national GHG inventories.

4.2. Contribution of Plant Science Innovations to Land Management Changes

Greenhouse gas (GHG) data has shown that agricultural practices can lead to emissions of CO_2. But this negative environmental effect can be turned into a positive if certain agricultural practices are adopted, specifically the use of conservation tillage and reduction of summer fallow.

In conservation tillage, crops are grown with minimal soil tillage. Broad spectrum herbicides are absolutely essential for effective weed control with conservation tillage in order to replace mechanical cultivation.

Cultivating summer fallow leads to greenhouse gas emissions and the practice had been used for decades on millions of acres in the Canadian Prairies. Despite the disastrous experience with the erosion of summer fallowed fields during prolonged droughts in the 1930s, this traditional practice continued in Canada and the U.S. for several reasons, the chief of which were: (a) to conserve soil moisture; and (b) to control weeds through cultivation. Plant science innovations have been essential to the dramatic decline of cultivated summer fallow. Modern herbicides used in concert with minimum tillage machinery provided effective weed control and soil moisture conservation without cultivated summer fallow. This let growers convert their summer fallow acres to production acres through the 1990s. This trend accelerated once modern plant breeding provided herbicide tolerant varieties, especially canola, that could be grown using herbicides conducive to minimum tillage operations. As with the general adoption of conservation tillage practices, low residue, broad spectrum herbicides and new herbicide tolerant varieties from modern plant breeding have been technological catalysts for reductions in cultivated summer fallow and a reduction in both greenhouse gas emissions and soil erosion.

In 1990, agronomic management of mineral soils led to a net removal of about -2,000 Gg CO_2 (GHG equivalents of CO_2). This net removal of CO_2 increased to -11,000 Gg CO_2 in 2012. The largest source of this increase in environmental benefit occurred because of the increasing use of conservation tillage and the decreasing use of cultivated summer fallow (see Table 28).

Table 28: Plant Science Innovations Enable Soil Conservation Practices that Reduce CO_2 Emissions

Categories		Land Management Change (LMC)	Emissions/Removals (Gg CO_2)[1]							
			1990	2000	2005	2008	2009	2010	2011	2012
Total Cropland Remaining Cropland			-1 500	-7 000	-10 000	-10 000	-10 000	-10 000	-10 000	-10 000
Cultivation of Histosols			300	300	300	300	300	300	300	300
Liming			200	270	290	290	290	290	290	290
Perennial Woody Crops			60	90	40	30	30	20	20	- 10
Total Mineral Soils			-2 000	-7 400	-10 000	-11 000	-11 000	-11 000	-11 000	-11 000
	Change in Crop Mixture	Increase in Perennial	-1 200	-3 000	-4 500	-4 700	-4 700	-4 700	-4 600	-4 600
		Increase in Annual	3 500	3 800	3 700	3 900	4 000	4 100	4 200	4 300
	Change in Tillage	Conventional to Reduced Tillage	- 870	- 960	- 860	- 790	- 760	- 730	- 710	- 680
		Conventional to No-till	- 540	-2 500	-3 500	-3 700	-3 800	-3 800	-3 800	-3 900
		Other	- 1	- 250	- 600	- 720	- 750	- 770	- 800	- 820
	Change in Summerfallow (SF)	Increase in SF	1 700	1 400	1 300	1 200	1 200	1 100	1 100	1 100
		Decrease in SF	-4 800	-7 100	-7 700	-8 000	-8 100	-8 200	-8 300	-8 400
Land Conversion—Residual Emissions[2]			170	1 400	1 700	1 800	1 900	1 900	1 900	1 900

Notes:
1. Negative sign indicates removal of CO_2 from the atmosphere.
2. Net residual CO_2 emissions from the conversion of forest land and grassland to cropland that occurred more than 20 years prior to the inventory year, including emissions from the decay of woody biomass and DOM.
NO = Not occurring

Source: National Inventory Report 1990-2012: Greenhouse Gas Sources and Sinks in Canada

Both of these trends are enabled by the use of plant science innovations and would be impossible without these technologies. This net carbon sink due to the adoption of conservation tillage practices (from -1,411 Gg in 1990 to -5,400 Gg in 2012) is substantiated by a net total increase of nearly 15 million hectares under no-till and conservation tillage over the 1991-2011 period (see Table 29). The net carbon sink from the decrease in summer fallow area increased from 2,100 Gg in 1990 to 7,300 Gg in 2012. The combined carbon sink from both benefits increased from 3,511 Gg in 1990 to 12,700 Gg in 2012, an increase of 9,189 Gg CO_2 per year.

4.3. Contribution of Plant Science Innovations to Reductions in Fossil Fuel Use

It is difficult to assess and model fuel savings attained through the use of crop protection/plant biotechnology products over a time frame consisting of many decades. The fuel picture is confounded with trends that include major changes in fuel efficiency in farm machinery technology and scale of equipment.

It is, however, possible to examine fuel use in two major trends in order to get a sense of the degree of the contribution that modern crop protection and plant biotechnology has made to reductions in fossil fuel use in Canada. Extension services routinely gather production costs and monitor inputs. Two provinces, Ontario and Saskatchewan, have current information on fuel usage on a per acre basis that differentiates between fuel consumption for conventional tillage and fuel consumption for conservation tillage.

Ontario puts the fuel consumption at 39.5 L per hectare for conventional tillage and 29.6 L per hectare for conservation tillage regimes – a savings of 25 per cent of total fuel consumption due to switching to conservation tillage. Saskatchewan puts fuel usage for cropped acres at 49.4 L per hectare for conventional tillage and 34.6 L per hectare for direct seeding systems – a total of 30 per cent reduction in consumption of fuel. For fallow acreage, fuel use drops from 24.7 L per hectare down to about 5 L per hectare if crop protection products are used to control weeds as opposed to tillage.

According to Statistics Canada data, there were an average about 29 million hectares of land devoted to growing field crops (including special crops) for the period 1991 through 2011.

Table 29 compares the acreages tilled by tillage regime for 1991 to the acreages tilled by different tillage regimes every 5 years to 2011. Applying the range of fuel usages for Ontario and Saskatchewan described above, conservation tillage and no-till systems have led to a reduction of the use of fossil fuels in Canada per year from a level of between 1.06 to 1.3 billion litres per year in 1991, to 0.93 to 1.1 billion litres per year in 2011 – a savings of between 126 to 194 million litres per year.

Table 29: Estimated Fuel Use Reductions and Resulting GHG Reductions

Land management practices		1991	1996	2001	2006	2011
Conventional tillage	Area (ha)	19,986,611	15,334,293	12,039,711	8,140,025	5,624,277
	Fuel (millions L)	790.2 to 987.8	606.3 to 757.8	476.0 to 595.0	321.8 to 402.3	222.4 to 278.0
Conservation tillage	Area (ha)	7,091,001	8,766,760	8,870,230	7,427,910	7,265,974
	Fuel (millions L)	210.3 to 245.3	260.0 to 303.3	263.0 to 306.9	220.3 to 257.0	215.5 to 251.4
No-till or zero-till	Area (ha)	1,951,154	4,591,779	8,823,482	13,480,814	16,689,838
	Fuel (millions L)	57.9 to 67.5	136.2 to 158.9	261.6 to 305.2	399.7 to 466.4	494.9 to 577.4
Total	Area (ha)	29,028,766	28,692,831	29,733,424	29,048,749	29,580,090
	Fuel (millions L)	1,058.3 to 1,300.6	1,002.4 to 1,220.0	1,000.7 to 1,207.1	941.8 to 1,125.6	932.7 to 1,106.7
	Fuel Savings (millions L)	**55.9 to 80.6**	**57.7 to 93.4**	**116.5 to 174.9**	**125.6 to 193.9**
	GHG Reductions (tonnes)*	**201,405 to 290,154**	**207,554 to 336,405**	**419,405 to 629,819**	**452,203 to 697,923**

Source: Statistics Canada. *Table 004-0010 - Census of Agriculture, selected land management practices and tillage practices used to prepare land for seeding*

* Based on a Canadian average conversion rate of 3.6kgs in GHG reductions per litre of diesel fuel ($S\&T^2$ Consultants Inc.)

The GHG reductions from the fuel savings from tillage changes on the existing land are also shown in Table 29, totalling between about 450,000 and 700,000 tonnes per year by 2011.

On top of this total, there are fuel savings that come from the reduction in cultivated summer fallow and the adoption of "chem fallow". Averaged over the 2.8 million hectares of cultivated summer fallow still conducted annually, this savings adds up to 56 million litres of fuel per year. There are also very large fuel savings from the cultivated cropland that is avoided by the use of plant science innovation. From Table 29 the average fuel use per ha in 2011 was 31.5 to 37.4 L/ha. The fuel use avoided on the 14.2 million additional hectares that would be required without plant science innovation would be an additional 448 to 532 million litres, producing between 1.6 and 1.9 million tonnes of GHG emissions.

In summary, conservation tillage, enabled by the use of crop protection products and plant biotechnology, saves between 126 and 194 million litres of fuel per year on the existing cropland. Reductions in cultivated summer fallow – enabled by pest control products – save an additional 56 million litres per year. Finally, fuel savings on the avoided cultivation of 14.2 million hectares saves an additional 448 to 532 million litres. The total reduced use of diesel fuel is 630 to 780 million litres per year. Total GHG reductions from this reduced fuel use amount to almost 2.3 to 2.8 million tonnes per year.

4.4. Other Non-Quantified Environmental Impacts

Water Use

Alberta Water Use - Case Study

No-till agriculture results in significantly higher soil water conservation, which can greatly reduce the need to irrigate in semi-arid and arid crop growing conditions. Alletto et al. found that conservation tilled corn was "more efficient in the use of water, especially that from irrigation". In a 2010 paper, Grassini reported that for corn fields with pivot irrigation systems and no-till was 41% more water efficient. Similarly, a 2001 overview of the impact of water-use efficiency (Hatfield et al 2001) found that appropriate tillage systems can reduce water use by 25-40%. The real advantage of no-till systems is to reduce water use in areas that do not receive optimal rainfall. Water use is especially important in Alberta, where semi-arid plains require much more irrigation than the rest of the country. Approximately 70% of all irrigation in Canada is for crop production in Alberta.[7]

Between 1991 and 2012, Alberta experienced a significant drop in the amount of water used for irrigation, which aligns with a corresponding increase in the area using no-till agriculture from 3% in 1991 to 65% in 2011. Over the same time period, the irrigation productivity index in Alberta has nearly doubled from 6kg to about 11 kg of dry matter per cubic metre of water.[8]

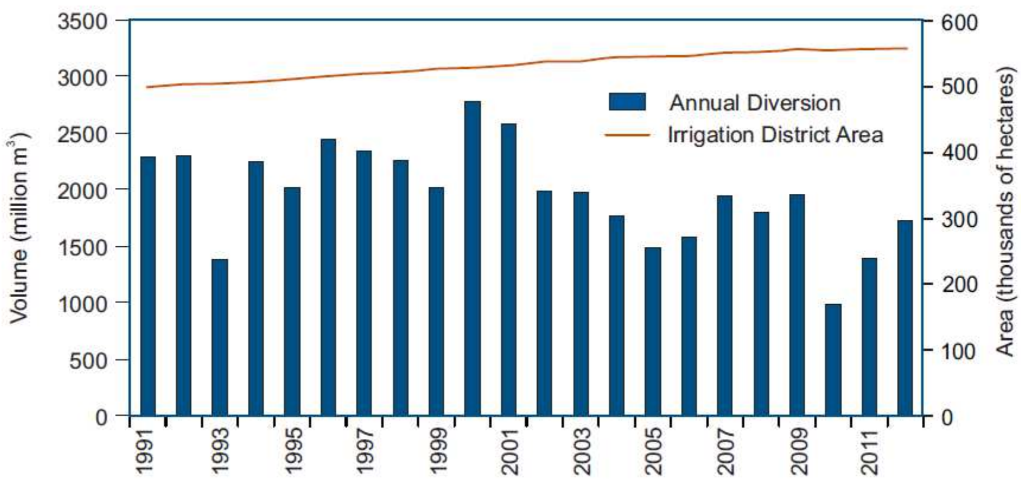
[7] Statistics Canada. Table 153-0099 - Farm irrigation status and irrigated crop area, by province, every 2 years (number unless otherwise noted), CANSIM (database)
[8] See Alberta Agriculture and Rural Development, 2014, page 5.

Some of this impact is explained by a trend towards low-pressure pivot irrigation systems and away from gravity systems.

Figure 3 below shows the water use and irrigated area in Alberta over the past 30 years. Between 1991 and 2012, the water used for irrigation decreased from about 2.3 billion m^3 to 1.65 billion m^3, a reduction of 650 million m^3, while the area irrigated increased by 600,000 hectares.

Assuming that half of the improvement was due to improved irrigation practices and half was due to reduced tillage conserving moisture, there was a reduction of water use of more than 300 million m^3 that could be attributed to plant science innovation.

Figure 3: Water-Use in Alberta



Source: Alberta Agriculture and Rural Development, 2014, page 11

4.5. Summary

The documented environmental benefits are summarized in the following table. On an average annual basis, plant science innovations generate about 29 million tonnes of GHG reductions per year compared to the counterfactual (agricultural production without plant science innovations).

Table 30: Summary of Annual GHG Reductions and Other Environmental Benefits

Source of GHG Reductions	Annual Amount of GHG Reductions
Avoided land clearing	17.5 million tonnes
Reduced summer fallow	5.2 million tonnes
Reduced tillage soil carbon	3.99 million tonnes
Reduced tillage fuel GHG	654 to 900 thousand tonnes
Reduced fuel use on avoided land	1.61 to 1.92 million tonnes
Total GHG emission benefit	28.8 to 29.3 million tonnes

Other Benefits	
Reduced fuel use, litres	630 to 780 million litres/year
Reduced water use	300 billion litres/year

5. Social Benefits

5.1. Consumer Impacts

This section measures the impact on Canadians' food budgets by looking at how an average household's food budget would increase if food products were priced at organic levels. This analysis understates the impact on food budgets, because it does not consider how higher input costs would affect the price of food products.

Organic farmers' reliance on higher levels of labour, the lower yields of organic farming generally makes organic fruit and vegetable and other food prices much higher than conventionally grown food. In a 2013 study, Shahidul Islam surveyed three Canadian grocers and reported the organic price premiums across a variety of products.

Table 31: Organic Price Premium for Various Grocery Store Products

Food Group	Estimated Price Premium (% above conventional)
Fresh Fruits	46.7%
Fresh vegetables	52.0%
Dry snacks and crackers	71.8%
Rice, wheat and pasta	124.4%
Breakfast cereals	31.3%
Sugar, syrup and honey	89.5%
Canned fruits and vegetables	111.4%
Ready-to-eat canned foods	55.5%
Jam, jelly and spread	105.7%
Salad dressings, ketchup and sauces	76.0%

Source: Islam, 2013

As a result, if farmers exclusively used organic farming methods, the higher prices would result in substantially higher food costs for Canadians. Canadians who are unable or unwilling to pay higher prices for organic food would be particularly disadvantaged.

Table 32: Estimated Impact of Plant Science Innovations on the Average Canadian Household Budget, 2013

	Average annual spending per Canadian household	Estimated Price Premium (% above conventional)	Total Budget Impact
Bread and unsweetened rolls and buns	$272	31.3%	$85.14
Cookies and crackers	$119	71.8%	$85.44
Other bakery products	$188	31.3%	$58.84
Rice and rice mixes	$36	124.4%	$44.78
Pasta products	$56	124.4%	$69.66
Other cereal grains and cereal products	$231	31.3%	$72.30
Fresh fruit	$434	46.7%	$202.68
Preserved fruit and fruit preparations	$191	105.7%	$201.89
Fresh vegetables	$500	52%	$260.00
Frozen and dried vegetables	$40	55.5%	$22.20
Canned vegetables and other vegetable preparations	$114	111.4%	$127.00
Condiments, spices and vinegars	$220	76.0%	$167.20
Snack food	$75	71.8%	$53.85
Total		**55.3%**	$1,450.98

Source: Statistics Canada CANSIM Table 203-0028; Islam 2013. Assumes that 3% of Canadians' budgets are already spent on organic produce, based on Organic Trade Association figures.

Given the price premium of organic products and Canadian spending habits, in order to buy the same basket of organic produce, the average Canadian household would need to spend 55.3% more, or an extra $1,450 per year. However, the Islam study did not include a number of key food products that benefit from plant science innovations, such as dairy and meat products.

Other studies in the U.S. examined a more complete basket of food items and the impact of organic prices on food expenditures. In their study, *Examining the Cost of an All-Organic Diet*, Brown and Sperow (2005) examined the impact that buying organic food would have on an American family of four, using a basket of food items from the United States Department of Agriculture's (USDA) "Thrifty Food Plan". The study found that an average family would spend 49% more for an all-organic diet. The report also cites a detailed 1999 U.S. study that placed the organic price premium at 70%.

The USDA Agricultural Marketing Service (AMS) maintains a comprehensive dataset on organic vs. conventional food pricing, with monthly and annual prices over a period of years for major commodities such as vegetables, fruits, poultry and eggs, grains and feedstuffs, and fluid milk products.[9] For 2013, organic fruit carried a 57% price premium over conventional grown fruit, and organic vegetables were priced at a 100% premium over conventional. Price data from

[9] Price data available at http://www.ers.usda.gov/data-products/organic-prices.aspx and http://www.ams.usda.gov/market-news

various U.S. National Retail Reports show organic price premiums across a range of commodities: 46% for butter, 110% for milk, 104% for eggs, 103% for wheat, 104% for soybeans, and 246% for corn.

Based on these various sources, the 55% price premium for organic food calculated in Table 32 of appears to be conservative.

According to Statistics Canada, the average Canadian household spent $7,980 on food in 2013. Applying the price premium for organic food of 55% to all food purchases, we estimate that the overall benefits to consumers of plant science innovations amounts to over $4,400 for each of the 13.8 million households in Canada, for a total of more than $60 billion in food expenditure savings for Canadians per year.

5.2. Public Health Benefits

Cooper and Dobson (2007) chronicle the literature linking pesticide use to year-round availability of inexpensive and good quality fresh fruit and vegetables, and the resulting health benefits of diets containing fresh fruit and vegetables. They also summarize the literature on the public health benefits of pest control products worldwide, including reduced mortality and morbidity from pesticide use to manage the incidence of various diseases, such as malaria, yellow fever, and encephalitis. In Canada, pesticide use plays a key role in limiting exposure to the West Nile virus.

There are numerous recent examples from the literature that demonstrate how pest control products play a key role in protecting human health, particularly from arthropod-vectored diseases, and also in reducing microbial contamination and the associated production of fungal toxins. Often overlooked is the use of chlorine and other disinfectants, all of which are registered pest control products, in water treatment to eliminate bacterial contaminants in drinking water. Disasters occur when public water supplies are inadequately treated, as evidenced by the outbreak of cryptosporidium in a Wisconsin water supply in 1993 (MacKenzie et al. 1994) and the water-borne outbreak of pathogenic E. coli in Walkerton, Ontario in 2000 which was definitively connected to inadequate chlorination (Hrudey et al. 2003).

RIAS Inc. (2006) cites other public health benefits related to the impacts of herbicide treatments in agriculture and non-agricultural uses on temperature moderation, pollutant filter for water quality, oxygen release, pollen allergy control, noise abatement, glare reduction and recreational activities.

6. Overall Value to Canadians

This section provides a final tally of the overall value to Canadians of plant science innovations, from a social welfare perspective, based on the economic, environmental and social benefits examined in the previous sections of this report.

Economic Benefits to Canadians

Section 3 estimated the economic impacts of plant science innovations across the value chain, and determined that these technologies generate $9.8 billion in GDP in Canada, as well as $4.7 billion in income and over 131,600 jobs for Canadians.

This economic activity generates $1.8 billion in taxes for governments across Canada.

Environmental Benefits to Canadians

In Section 4, GHG reductions were estimated from the contribution of plant science innovations to carbon sinks due to the adoption of conservation tillage practices amount to about 3 million tonnes per year.

Fuel reductions due to conservation tillage practices from use of plant science innovations save over 125 million litres of fuel per year. Reductions in summer fallow, enabled by herbicides, save an additional 56 million liters per year. The total reduced use of diesel fuel is over 181 million litres per year. Total GHG reductions from this reduced fuel use amounts to almost 684,000 tonnes per year.

In total, the annual GHG reductions from the use of plant science innovations in agriculture amount to a 28.98 to 29.52 million tonnes per year.

The estimated value to society of avoided damages from GHG reductions is based on the climate change damages avoided at the global level. These damages are usually referred to as the social cost of carbon (SCC). Environment Canada estimates that SCC values range from $28/tonne to $112/tonne of CO_2 in 2013, but note that some studies have produced values exceeding $1,000/tonne of CO_2.[10] Using the conservative range of SCC values ($28 to $112/ per tonne) and the GHG reductions calculated in Section 4, the value to society of carbon offset through plant science innovation is between about $816 million to $3.3 billion per year.

[10] See the Regulatory Impact Analysis Statement for the Order Declaring that the Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations do not apply in Nova Scotia (Canada Gazette Vol. 148, No. 26 — June 28, 2014) at http://www.gazette.gc.ca/rp-pr/p1/2014/2014-06-28/html/reg3-eng.php.

Social Benefits to Canadians

Section 5 estimated that Canadians save more than $60 billion on their food expenditures every year due to the use of plant science innovations in food production.

Total Value to Canadians of Plant Science Innovations

In total, the benefits to Canadians of plant science innovations, based on the sum of quantified economic, environmental and social benefits summarized above, totals more than $70 billion per year.

7. Glossary

There are numerous terms and acronyms used in the area of biotechnology that can be confusing. Also, many countries use the same term to mean different things. For example, the European Union's definition of GM is the same as Canada's interpretation of GE. The following is the Canadian Food Inspection Agency's (CFIA) attempt at addressing some commonly used terms, of which only "biotechnology" and "novel trait" are used in CFIA legislation.

"**Biotechnology**" means the application of science and engineering in the direct or indirect use of living organisms, or parts or products of living organisms, in their natural or modified forms. This term is very broad and includes the use of traditional or conventional breeding, as well as more modern techniques of biotechnology including gene mapping, DNA sequencing, genetic modification, functional genomics, diagnostics and cloning.

"**Modern biotechnology**" is used to distinguish newer applications of biotechnology, such as genetic engineering and cell fusion from more conventional methods such as breeding, or fermentation.

Most often the term "biotechnology" is used interchangeably with "modern biotechnology".

"**Conventional breeding**" or "**selective breeding**" means propagating plants or animals sexually, selecting for certain traits. Using selective cross-breeding, people can produce different varieties of plants and breeds of animals.

GM stands for "**genetically modified**". An organism, such as a plant, animal or bacterium, is considered genetically modified if its genetic material has been altered through any method, including conventional breeding. A "GMO" is a genetically modified organism.

GE stands for "**genetically engineered**". An organism is considered genetically engineered if it was modified using techniques that permit the direct transfer or removal of genes in that organism. Such techniques are also called recombinant DNA or rDNA techniques.

Some international agreements like the Cartagena Protocol on Biosafety use terms like "**living modified organism**" (**LMO**). The Protocol defines a LMO as a microorganism, plant, or animal that has been derived through modern biotechnology-using techniques such as recombinant DNA-that is capable of transferring or replicating its genetic material (DNA, or "deoxyribonucleic acid", is the genetic material found in all living organisms).

"**Transgenic**" organisms have a gene from another organism moved into them. For example, the plant product known as "Bt. corn" is a transgenic plant because it has a gene from the bacterium *Bacillus thuringiensis*, or Bt. That gene produces a protein with pesticidal properties that, when incorporated into a plant, allows the plant to produce this protein, thus transferring the bacteria's natural defence to the plant.

"**Mutagenesis**" is the use of methods to physically change or "mutate" the genetic sequence, without adding DNA from another organism. Various chemicals and ionizing radiation can be used to invoke these changes. "Site-directed mutagenesis" can also be used to invoke changes in specific genes. In plants, such agents are used to change a plant's genetic sequence, and the plant can pass on these new characteristics to its offspring.

Novel - A new product may be considered "**novel**" if it has:

- a new trait(s) or characteristic(s), or
- a changed trait(s) or characteristic(s), or
- a new use as a food or livestock feed

Novel trait - a new characteristic or attribute scientifically trait introduced to a plant, a food or food ingredient. The word "novel" means "new"-a PNT is a plant that has a new trait or characteristic. A plant is considered to be a PNT if has trait(s) that are novel to that species in Canada. That is:

- the new trait is not present in stable, cultivated populations of the plant species in Canada, or
- the trait in the plant species is present at a level significantly outside the range of that trait in stable, cultivated populations of that plant species in Canada.

Traditionally, plants have been given new traits through selective breeding. Modern science gives plant breeders newer methods of introducing novel traits into plants, including mutagenesis and genetic engineering/rDNA. Canada is the only country that assesses plants and novel livestock feeds that have new traits introduced by any technique, including traditional breeding techniques and mutagenesis because the new traits may have an impact on the environment.

A "**novel feed**" is livestock feed comprising an organism or organisms, or parts or products thereof, that:

a) is not set out in Schedule IV or V of the Feed Regulations, or
b) has a novel trait (as defined in the Feeds Regulations).

Novel livestock feeds are composed of or derived from one of these sources: microbial, plants, or animal.

PNT stands for a "**Plant with a Novel Trait**": a plant with a characteristic not normally found in that species or a trait expressed outside the normal range of similar existing characteristics in that species. Novel traits are introduced via genetic modification techniques including conventional selective breeding, genetic engineering or mutagenesis. Most genetically engineered plants are PNTs but not all PNTs are created by genetic engineering. A livestock feed (including feeds from non-traditional sources and feeds used or approved in other countries) is also considered novel until listed in Schedule IV or V of the Feeds Regulations. Experimental PNTs (e.g., unapproved novel human or animal food crops, horticultural and marine plants, trees) are subject to regulatory controls by CFIA and extensive safety assessments before approval for unconfined release.

PMF stands for plant molecular farming; the cultivation of plants for industrial, medicinal or scientifically useful biomolecules (e.g., vaccines, antibodies, pharmaceuticals, industrial enzymes) rather than traditional uses as foods, feeds or fibres.

8. References

Adenle, Ademola A. "Global Capture of Crop Biotechnology in Developing World over a Decade." *Journal of Genetic Engineering and Biotechnology* 9, no. 2 (December 2011): 83–95. doi:10.1016/j.jgeb.2011.08.003.

Agriculture and Agri-Food Canada. *Alternative Cropping Systems Study - Scott, Saskatchewan.* Report, January 8, 2013. http://www.prairiesoilsandcrops.ca/articles/volume-5-8-screen.pdf.

Aktar Md. Wasim, Dwaipayan Sengupta Ashim Chowdhury (2005) "Impact of pesticides use in agriculture: their benefits and hazards" Interdisciplinary Toxicology Vol. 2(1): 1–12

Aktar Md. Wasim, Dwaipayan Sengupta, and Ashim Chowdhury (2009) "Review Article: Impact of pesticides use in agriculture: their benefits and hazards" *Interdisciplinary Toxicology* 2009 Vol. 2(1): 1–12.

Alberta Agriculture and Rural Development. 2014. Alberta's irrigation – a strategy for the future. Irrigation and Farm Water Division, Alberta Agriculture and Rural Development, Lethbridge, Alberta, Canada. http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/irr14885/$file/2014-alta-irrig-strategy.pdf

Allara M., S. Kugbei, F. Dusunceli and G. Gbehounou (2012) "Coping with changes in cropping systems: plant pests and seeds" Plant Production and Protection Division, FAO, Rome

Andersen Laura Mørch and Thomas Bøker Lund (2011) "Digging deeper: How do different types of organic consumers influence the increasing organic market share?" FOI Working Paper 2011 / 15 Institute of Food and Resource Economics University of Copenhagen

Ariyawardana Anoma, Ramu Govindasamy and Venkata Puduri (2009) "Consumers' Willingness to Pay for Organic Ethnic Specialty Produce in the U.S.A." International Conference on Applied Economics – ICOAE 2009

Bale J. S., J. C. van Lenteren, and F. Bigler (2008) "Biological control and sustainable food production" Philosophical Transactions of the Royal Society Bulletin (2008) 363, 761–776

Barfoot, Peter and Graham Brooks (2014) "Key global environmental impacts of genetically modified (GM) crop use 1996–2012" *GM Crops & Food: Biotechnology in Agriculture and the Food Chain* 5:2, 149–160; April/May/June 2014

Barfoot, Peter and Graham Brooks. "GM Crops: The Global Economic and Environmental Impact - The First Nine Years 1996-2004," September 19, 2005. http://www.agbioforum.org/v8n23/v8n23a15-brookes.htm.

Berman, Judit, Changfu Zhu, Eduard Pérez-Massot, Gemma Arjó, Uxue Zorrilla-López, Gemma Masip, Raviraj Banakar, et al. "Can the World Afford to Ignore Biotechnology Solutions That Address Food Insecurity?" *Plant Molecular Biology* 83, no. 1–2 (September 1, 2013): 5–19. doi:10.1007/s11103-013-0027-2.

Brookes, Graham, and Peter Barfoot (2014) "Economic Impact of GM Crops: The Global Income and Production Effects 1996–2012" *GM Crops & Food* 5, no. 1 (January 2014): 65–75. doi:10.4161/gmcr.28098

———. "Global Impact of Biotech Crops: Environmental Effects, 1996–2010." *GM Crops & Food* 3, no. 2 (April 2012): 129–37. doi:10.4161/gmcr.20061.

Brown, Cheryl and Mark Sperow (2005). "Examining the Cost of an All-Organic Diet". Journal of Food Distribution Research, Volume 36, Number 01, March 2005.

Canadian Food Inspection Agency (2007). Regulation of Agricultural Biotechnology in Canada. ISBN 978-0-662-45503-5. http://publications.gc.ca/collections/collection_2007/cfia-acia/A104-24-2007E.pdf

——— (2012). The Safety Assessment Process for Plants with Novel Traits http://www.inspection.gc.ca/plants/plants-with-novel-traits/general-public/assessment-process/eng/1338189630096/1338189929476

——— (2014). Regulating Agricultural Biotechnology in Canada: An Overview http://www.inspection.gc.ca/plants/plants-with-novel-traits/general-public/overview/eng/1338187581090/1338188593891#fnb1

Canadian Produce Marketing Association (CPMA 2012) "Fresh Facts: Integrated Pest Management" http://www.cpma.ca/Files/Fresh%20Facts%20Integrated%20Pest%20Management.pdf

Catherine Bagdley et al. "Organic Agriculture and the Global Food Supply." *Renewable Agriculture and Food Systems: 22(2); 86–108*, n.d. doi:doi:10.1017/S1742170507001640.

Carpenter, Janet E. (2011) Impact of GM crops on biodiversity, GM Crops, 2:1, 7-23

Cavigelli, Michel A., Beth L. Hima, James C. Hanson, John R. Teasdale, Anne E. Conklin, and Yao-chi Lu. "Long-Term Economic Performance of Organic and Conventional Field Crops in the Mid-Atlantic Region." *Renewable Agriculture and Food Systems* 24, no. 2 (June 2009): 102–19. doi:http://dx.doi.org/10.1017/S1742170509002555.

Centre For the Study Of Living Standards (2011) Measuring The Contribution Of Modern Biotechnology To The Canadian Economy, CSLS Research Report 2011-18. December 2011

Committee on the Impact of Biotechnology on Farm-Level Economics and Sustainability; National Research Council. *Impact of Genetically Engineered Crops on Farm Sustainability in the United States*. Accessed November 6, 2014. http://www.nap.edu/catalog.php?record_id=12804.

Consumer Reports (2015). The cost of organic food. March 19, 2015

Cooper Jerry and Hans Dobson (2007) "The benefits of pesticides to mankind and the environment" *Crop Protection* Accepted 19 March 2007

Council of Canadian Academies, 2013. The State of Industrial R&D in Canada. The Expert Panel on Industrial R&D in Canada, Council of Canadian Academies.

CropLife Canada (2011). Cultivating a vibrant Canadian economy.

——— (undated). CropLife Canada Crop Protection Stewardship http://www.croplife.ca/protecting-people-and-the-environment/crop-protection-stewardship

——— (undated). CropLife Canada Plant Biotechnology Stewardship http://www.croplife.ca/protecting-people-and-the-environment/plant-biotechnology-stewardship

De Ponti, Tomek, Bert Rijk, and Martin K. van Ittersum. "The Crop Yield Gap between Organic and Conventional Agriculture." *Agricultural Systems* 108 (April 2012): 1–9. doi:10.1016/j.agsy.2011.12.004.

Delbridge Timothy A., Jeffrey A. Coulter, Robert P. King, and Craig C. Sheaffer (2010) "A Profitability and Risk Analysis of Organic and High-Input Cropping Systems in Southwestern Minnesota" Department of Applied Economics and Department of Agronomy and Plant Genetics, University of Minnesota, St. Paul, Minnesota, USA

Delbridge, Timothy A., Carmen Fernholz, Robert P. King, and William Lazarus. "A Whole-Farm Profitability Analysis of Organic and Conventional Cropping Systems." *Agricultural Systems* 122 (November 2013): 1–10. doi:10.1016/j.agsy.2013.07.007.

Einsiedel Edna F. (1998) "The Market for Credible Information in Biotechnology" in Bartha Maria Knoppers and Alan Mathios (eds.), (1998) *Biotechnology and the Consumer*, A Research Project Sponsored by the Office of Consumer Affairs of Industry Canada, Kluwer Academic Publishers, pages 47-86

Environment Canada. National Inventory Report - The Canadian Government's Submission to the UN Framework Convention on Climate Change. April 11, 2014

Felsot Allan S. (2011) *Pesticides & Health: Myths vs. Realities* A Position Paper of the American Council on Science and Health June 1511

Fernandez-Cornejo, Jorge, Seth Wechsler, Mike Livingston, and Lorraine Mitchell (2014). Genetically Engineered Crops in the United States, ERR-162 U.S. Department of Agriculture, Economic Research Service, February 2014.

Gianessi Leonard P. (2013) "The increasing importance of herbicides in worldwide crop production" Pest Management Science; 69: 1099–1105 Published online in Wiley Online Library: 9 August 2013

Govindasamy Ramu and John Italia (1999) "Predicting Willingness-to-Pay a Premium for Organically Grown Fresh Produce" Journal of Food Distribution Research, July 1999 pp. 44-53

Grebitus Carola, Chengyan Yue, Maike Bruhn, and Helen H. Jensen (2007) "What Affects Consumption Patterns of Organic and Conventional Products?" Selected Poster Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Portland, 2007

Health Canada (2005). The Regulation of Genetically Modified Food. ISBN 0-662-69374-4. http://www.hc-sc.gc.ca/sr-sr/pubs/biotech/reg_gen_mod-eng.php

——— (2006). Guidelines for the Safety Assessment of Novel Foods http://www.hc-sc.gc.ca/fn-an/legislation/guide-ld/nf-an/guidelines-lignesdirectrices-eng.php

——— (2013). *Value Assessment of Pest Control Products* Regulatory Directive DIR2013-03 Prepared by the Pest Management Regulatory Agency 10 September 2013

——— (2015a). Pest Control Products Sales Report for 2012

——— (2015b). Pest Management Regulatory Agency - Annual Report 2013-2014 http://www.hc-sc.gc.ca/cps-spc/pubs/pest/_corp-plan/annual_2013-2014_annuelle/index-eng.php#a5

——— (undated). The Regulation of Pesticides in Canada http://www.hc-sc.gc.ca/cps-spc/pubs/pest/_fact-fiche/reg-pesticide/index-eng.php

——— (undated). Frequently Asked Questions - Biotechnology and Genetically Modified Foods http://www.hc-sc.gc.ca/fn-an/gmf-agm/fs-if/faq_1-eng.php

James, Clive (2012) ISAAA-Brief-44-2012. http://www.isaaa.org/resources/publications/briefs/44/download/isaaa-brief-44-2012.pdf

Klümper, Wilhelm, and Matin Qaim (2014) "A Meta-Analysis of the Impacts of Genetically Modified Crops: e111629." *PLoS One* 9, no. 11 (November 2014): e111629. doi:http://dx.doi.org/10.1371/journal.pone.0111629

LMC International. The Economic Impact of Canola on the Canadian Economy. Report prepared for the Canola Council of Canada. October 2013

Lusk Jayson L., Mustafa Jamal, Lauren Kurlander, Maud Roucan, and Lesley Taulman (2005) "A Meta-Analysis of Genetically Modified Food Valuation Studies" *Journal of Agricultural and Resource Economics* 30(1):2844

Phillips MacDougall (2010). The Cost of New Agrochemical Product Discovery, Development and Registration and Research & Development predictions for the future. Crop Life America, January 2010.

——— (2011). The cost and time involved in the discovery, development and authorisation of a new plant biotechnology derived trait. CropLife International, September 2011.

——— (2012). R&D trends in Crop Protection. ABIM Conference October 2012

Mahlein, Anne-katrin, Erich-christian Oerke, Ulrike Steiner, and Heinz-wilhelm Dehne. "Recent Advances in Sensing Plant Diseases for Precision Crop Protection." *European Journal of Plant Pathology* 133, no. 1 (June 1512): 197–209. doi:http://dx.doi.org/10.1007/s10658-011-9878-z.

Mallory, Ellen B., and Gregory A. Porter. "Potato Yield Stability under Contrasting Soil Management Strategies." *Agronomy Journal* 99, no. 2 (April 2007): 501–10.

McElroy David (2003) "Sustaining agbiotechnology through lean times" *Nature Biotechnology* 21(9) September 2003 996-1002

Merrill Scott C. (2012) *Predicting the effects of climate change on agricultural pest incidence: How secure is our food supply*? Department of Plant and Soil Science University of Vermont

Munkvold, Gary P., Clifford Watrin, Monika Scheller, Ronald Zeun, and Gilberto Olaya. "Benefits of Chemical Seed Treatments on Crop Yield and Quality." In *Global Perspectives on the Health of Seeds and Plant Propagation Material*, edited by Maria Lodovica Gullino and Gary Munkvold, 89–103. Plant Pathology in the 21st Century 6. Springer Netherlands, 2014. http://link.springer.com/chapter/10.1007/978-94-017-9389-6_7.

National Research Council. 2010. The Impact of Genetically Engineered Crops on Farm Sustainability in the United States. Washington, DC: National Academies Press.

Nazarko, Orla M., Rene C. Van Acker, Martin H. Entz, Allison Schoofs, and Gary Martens. "Pesticide Free Production of Field Crops: Results of an on-Farm Pilot Project." *Agronomy Journal* 95, no. 5 (October 2003): 1262–73.

Nicolia Alessandro, Alberto Manzo, Fabio Veronesi, and Daniele Rosellini (2013) "Review Article: An overview of the last 10 years of genetically engineered crop safety research" *Critical Reviews in Biotechnology* pp. 1-12

Oerke, E. -C., and H. -W. Dehne. "Safeguarding Production—losses in Major Crops and the Role of Crop Protection." *Crop Protection* 23, no. 4 (April 2004): 275–85. doi:10.1016/j.cropro.2003.10.001.

Oerke, E.-C. "Crop Losses to Pests." *The Journal of Agricultural Science* 144, no. 01 (February 2006): 31–43. doi:10.1017/S0021859605005708.

Palmer, Mike W., Julia Cooper, Catherine Tétard-Jones, Dominika Średnicka-Tober, Marcin Barański, Mick Eyre, Peter N. Shotton, et al. "The Influence of Organic and Conventional Fertilisation and Crop Protection Practices, Preceding Crop, Harvest Year and Weather Conditions on Yield and Quality of Potato (Solanum Tuberosum) in a Long-Term Management Trial." *European Journal of Agronomy* 49 (August 2013): 83–92. doi:10.1016/j.eja.2013.03.004.

Pimentel, David, and Michael Burgess. "Environmental and Economic Costs of the Application of Pesticides Primarily in the United States." In *Integrated Pest Management*, edited by David Pimentel and Rajinder Peshin, 47–71. Springer Netherlands, 2014. http://link.springer.com/chapter/10.1007/978-94-007-7796-5_2.

Pimentel, David, Paul Hepperly, James Hanson, David Douds, and Rita Seidel. "Environmental, Energetic, and Economic Comparisons of Organic and Conventional Farming Systems." *BioScience* 55, no. 7 (July 1, 2005): 573–82. doi:10.1641/0006-3568(2005)055[0573:EEAECO]2.0.CO;2.

Popp, József, Károly Pető, and János Nagy. "Pesticide Productivity and Food Security. A Review." *Agronomy for Sustainable Development* 33, no. 1 (January 1, 2013): 243–55. doi:10.1007/s13593-012-0105-x.

Posner, Joshua L., Jon O. Baldock, and Janet L. Hedtcke. "Organic and Conventional Production Systems in the Wisconsin Integrated Cropping Systems Trials: I. Productivity 1990–2002." *Agronomy Journal* 100, no. 2 (2008): 253. doi:10.2134/agrojnl2007.0058.

RIAS Inc. (2006) Assessment of the Economic and Related Benefits to Canada of Phenoxy Herbicides. October 2006

Ronald D. Knutson. "Economic Impacts of Reduced Pesticide Use In The United States: Measurement Of Costs And Benefits." In *AFPC Policy Issues Paper 99-2*, 1999. https://www.afpc.tamu.edu/pubs/1/148/99-2.pdf.

Serecon Inc. (2015, forthcoming). Draft Final Report. Application of Sustainable Agriculture Metrics to Western Canadian Field Crops. Prepared For Canadian Field Print Initiative

Seufert, Verena, Navin Ramankutty, and Jonathan A. Foley. "Comparing the Yields of Organic and Conventional Agriculture." *Nature* 485, no. 7397 (May 10, 2012): 229–32.

Islam, Shahidul (2013) "Retail Price Differential Between Organic and Conventional Foods".Proceedings of ASBBS Volume 20 Number 1. ASBBS Annual Conference: Las Vegas, February 2013

Statistics Canada. Table 001-0009 - Area, production and farm gate value of fresh and processed fruits, by province, annual, CANSIM

———. Table 001-0014 - Area, production and farm gate value of potatoes, by province, annual, CANSIM

———. Table 001-0010 - Areas, yield, production and average farm price of principal field crops, by province, annual, CANSIM

———. Table 001-0013 - Area, production and farm gate value of vegetables, by province, annual, CANSIM

———. Table 153-0115 - Direct plus indirect energy and greenhouse gas emissions intensity, by industry, annual, CANSIM

———. Table 203-0028 - Survey of household spending (SHS), detailed food expenditures, annual, CANSIM

Zentner, R. P., P. Basnyat, S. A. Brandt, A. G. Thomas, D. Ulrich, C. A. Campbell, C. N. Nagy, et al. "Effects of Input Management and Crop Diversity on Economic Returns and Riskiness of Cropping Systems in the Semi-Arid Canadian Prairie." *Renewable Agriculture and Food Systems* 26, no. 3 (September 2011): 208–23. doi:http://dx.doi.org/10.1017/S1742170510000591.

Appendices – Background Research and Analysis

Appendix 1 - The Evolving Role of Plant Science in Crop Improvement

Pest control products have been in use for generations but advances in biochemistry lead to the development of synthetic pest control products in the 1930s and, as their practical value was rapidly recognized, their use became widespread after World War II. From 1945 to 1965, organochlorines were used extensively in all aspects of agriculture and forestry, in protecting crops, wooden buildings and humans from many insect pests.

Discovery of a more effective group of insecticides, organophosphates, led to replacement of organochlorines. Certain organophosphates are systemic: unlike non-systemic pesticides, they are taken up by the plant's tissues and the plant then inhibits or kills the bacteria, fungi or parasites.

A third group of insecticides, carbamates, were discovered later and are less widely used – mainly against insect pests in potato and field crops while others are used for forest protection. The synthetic pyrethroid group of insecticides was introduced in the early 1970s, although natural source pyrethrum has been used for hundreds of years. The stability and effective insecticidal activity of synthetic pyrethroids led to increased use during the last few decades by producers of fruit, vegetable and corn crops. Their high insecticidal activity level means that producers can reduce application rates (in some cases to 100 grams/hectare).

Research into pesticides continued and the 1970s and 1980s saw the introduction of the world's greatest selling herbicide, glyphosate, the low use rate sulfonylurea and imidazolinone herbicides, as well as dinitroanilines and the aryloxyphenoxypropionate and cyclohexanediones families. For insecticides there was the synthesis of a third generation of pyrethroids, the introduction of avermectins, benzoylureas and Bt (Bacillus thuringiensis) as a spray treatment. This period also saw the introduction of the triazole, morpholine, imidazole, pyrimidine and dicarboxamide families of fungicides.

In the 1990s research activities concentrated on finding new pest control products which have greater selectivity and better resistance management, and have improved environmental and toxicological profiles. There has also been a refinement of mature pest control products in terms of use patterns with the introduction of new formulations, with lower residue and toxicity levels, that are friendlier to the environment, and more user-friendly for applicators. Many of these new pest control products can be applied at much lower rates, such as grams per hectare rather than kilograms per hectare.

Advancement of biopesticides has also taken place. Biopesticides fall into three main categories:

1. **Microbial pesticides** consist of a microorganism (e.g., bacteria, alga, fungus, protozoan, virus, mycoplasma or rickettsia and related organisms) as the active ingredient.

2. **Semiochemicals** are message-bearing substances produced by a plant or animal that evoke a behavioural response in individuals of the same or other species; some examples of semiochemicals are allomones, kairomones, pheromones, and synomones.
3. **Other non-conventional pesticides** are substances not covered by the above categories and include common food items, extracts, preservatives or additives, plant extracts and oils, commodity chemicals that have a range of non-pesticidal uses, other plant growth supplements, commonly used in the agricultural sector

In recent decades, advancements in pest management and modern plant breeding have led to significant changes in crop production practices leading to even greater yield gains and crop quality improvements. These changes include a massive move by producers away from ploughing and cultivation towards conservation (zero or minimum) tillage, as well as changes in the composition of pest control products (increased use of products with lower toxicity/ environmental impact coupled with reduced use of products with higher toxicity/environmental impact).

For example, development of herbicide tolerant varieties of crops has produced plants whose growth is not significantly affected by herbicides used on the weeds growing around them. Some plants are naturally tolerant to a specific herbicide, while others develop this tolerance in the evolutionary process of adapting to their environment. For many years, scientists and farmers have known that herbicide tolerance can be transferred from one plant to another through conventional breeding of farmed crops. Other herbicide-tolerant plants are developed through modern plant breeding techniques.

These types of plants were developed to help farmers control weeds that compete with crops for soil, space, water, and sunlight. This helps farmers produce higher yields. The herbicide controls the weeds in the field but the herbicide-tolerant crop is not affected.

Most modern plant breeding has so far delivered direct benefits mainly for crop production. But there are many products emerging from research and development pipelines that will provide more direct contributions to food quality and nutrition, drought resistance, environmental and health benefits, new biofuel and biofibre products, and as Integrated Pest Management (IPM) tools. Examples of these products include: rice with higher levels of iron and b-carotene (an important micronutrient which is converted to vitamin A in the body), low-asparagine potatoes (less susceptible to bruising); non-browning apples[11], corn with improved feed value; tomatoes with high levels of flavonols, which are powerful antioxidants; maize with improved phosphorus availability; plants for soil remediation that are tolerant to pollutants such as heavy metals and arsenic, low lignin trees for paper making and low lignin alfalfa for more digestible feed for cattle; drought tolerant maize; and edible vaccines from fruits and vegetables.

[11] In March 2015, Health Canada approved two genetically engineered apple varieties designed to resist browning that have been developed by the Canadian company Okanagan Specialty Fruits. Health Canada determined that "the changes made to the apple did not pose a greater risk to human health than apples currently available on the Canadian market. In addition, Health Canada also concluded that the Arctic apple would have no impact on allergies, and that there are no differences in the nutritional value of the Arctic apple compared to other traditional apple varieties available for consumption." See http://www.hc-sc.gc.ca/fn-an/gmf-agm/appro/arcapp-arcpom-eng.php

Appendix 2 - Management of the Sector

Regulatory Framework

Canada’s plant science sector is subject to a comprehensive and rigorous regulatory framework that is focused on safeguarding the health and the environment of Canadians.

The Canadian food safety system is highly regarded, both domestically and internationally. In November 2014 the Conference Board of Canada published its report “2014 World Ranking: Food Safety Performance”. Canada's food safety system tied for first place with Ireland in a comparison of 17 Organization for Economic Co-operation and Development (OECD) countries. While the report is not specific to crop protection products and plant biotechnology, the overall world ranking score was determined based upon 10 indicators, organized in three areas that are relevant to all aspects of food safety: risk assessment, risk management and risk communication. The report also found that public trust in food safety was the highest in Canada.

Regulation of Pest Control Products

The regulation and oversight of pest control products is a shared federal/provincial/territorial responsibility.

At the federal level, the Pest Management Regulatory Agency (PMRA), a branch of Health Canada, is responsible for regulating pest control products under the authority of the federal *Pest Control Products Act* (PCPA). The PMRA mandate is to prevent unacceptable risks to people and the environment from the use of these products. The PMRA is responsible for registering pest control products (pre-market assessment) for sale or use in Canada; re-evaluating registered products and setting maximum residue limits. The PMRA also encourages the development and application of sustainable pest management strategies and facilitates access to lower risk pest control products.

Only pesticides that are registered for use under the PCPA may be imported into, sold or used in Canada. However, provinces and territories may regulate the sale, use, storage, transportation and disposal of registered pesticides in their jurisdictions as long as the measures they adopt are consistent with any conditions, directions and limitations imposed under the PCPA or other federal legislation. Provinces and territories administer a pesticides management program that includes education and training programs, the licencing/certification of applicators, vendors and growers, and issuing permits for certain pesticide uses. Other important roles - carried out in cooperation with PMRA regional offices - are those of enforcement and compliance monitoring, and response to spills or accidents.

Regulation of Products of Modern Plant Breeding

The primary federal agencies involved in the regulation of plant biotechnology are the Canadian Food Inspection Agency (CFIA) and Health Canada (HC). The CFIA is the lead agency responsible for regulating plant biotechnology products mainly under the *Seeds Act* and the *Feeds Act*. CFIA is primarily responsible for environmental safety, as well as for inspection and monitoring so that regulated products continue to meet quality and safety standards after their approval. This inspection and monitoring function includes imported products of biotechnology.

HC, under the *Food and Drugs Act*, has primary responsibility for human health related issues and is responsible for setting standards for safety of the food supply, including food products of biotechnology (novel foods).

Industry Stewardship Practices

The plant science sector is committed to stewardship programs, processes, and practices to promote health, safety and environmental responsibility along the crop innovation pathway - from initial research and development of a product through to its disposal at the end of its life. CropLife Canada offers a series of programs focused on the responsible management of crop protection and plant biotechnology products.

Through these programs, CropLife Canada member companies collaborate with grower organizations and governments to ensure the Canadian agricultural industry has the solutions to be profitable and sustainable in the future. Participants in Stewardship*first*™ pledge to subscribe to specific guiding principles while continuing both internal and external corporate stewardship activities.

Appendix 3 - Measuring Economic Impacts

Literature Review of Economic Impacts

Generally, the economic impact of plant science innovations has focused on the on-farm impacts to yields, profitability, as well as various socioeconomic, environmental and health impacts. There have been a few relevant studies have estimated broader sector impacts for closely related industries such as the seed sector and plant science sector in Canada. The results of these papers and their methods have influenced this study. Literature that focuses primarily on yields is not included in the following review; however, results of those studies are summarized in Table 33 below.

Pest Control Product Impacts on Crop Production

Most studies measuring the economic impacts of pest management examine the effects on specific measures, but a few studies examine the economic effects across a broad range of crops. In a 2012 paper, Popp et al. found that pests, weeds, and diseases resulted in global crop losses of around 30% in corn, soybeans, and cotton. They estimated that the benefit to cost ratio of pesticide use in the U.S. for herbicides, insecticides, and fungicides was on average $6.5 of crop yield saved per $1 spent on pest management.

Oerke (2006) reports that although crop losses were stable from 1960 to 2003, various studies have found that "in many regions, [pest management measures] have enabled farmers to increase crop productivity considerably without losing an economically non-acceptable proportion of crops to pests."

Knutson's (1991) research shows that reducing pesticide has broad socioeconomic costs that must be taken into consideration when considering a ban for public health reasons. For example, the broader the group of pest control products eliminated the greater the impact on yields and the economic risks to farmers markedly increases as the number of alternatives for dealing with pests declines. There are also negative impacts on food security and the poor. Although negative health effects from direct exposure to pest control products are reduced, the substitutes for pest control products are often as bad as the pest control products they replace.

According to Gianessi (2013), herbicide use is becoming increasingly economically viable in developing countries and that its use reduces tillage, erosion, fuel use, greenhouse gas emissions, and nutrient run-off.

When comparing conventional versus organic systems from an economic perspective, the profitability is broadly similar. Lower yields and higher labour and management costs for organic farms are generally matched by a higher price premium for organic crops, fruits, and vegetables. This result follows competitive economic theory, which expects that the decision between farming organically and conventionally should be competitive, i.e. no extraordinary economic profits for one method over the other. The literature shows that this is only the case because of the higher price premiums for organic produce compared to conventional farming methods that use chemical pest management measures.

Pimental et al. (2005) found that conventional agriculture using fertilizer and pesticide had higher net returns per hectare than organic for soybeans and corn. In normal rainfall conditions, crop yields were significantly higher in the conventional, tilled systems, although the organic farming system slightly outperformed conventional in drought conditions. Pimental et al. found that organic systems had higher soil organic matter and farms spent less on fuels, but used more labour and had greater nitrate leaching.

Cavigelli et al.(2009) found that that no till and chisel till farming systems for corn and soybean had far greater yields compared to 3 different organic systems with 2-year, 3-year, and 4-6 year crop rotations. The significant price premium farmers received for organic produce made up for much of the higher costs and lower yields. However, their analysis did not include the additional marketing and post-harvest costs for organic crops.

A 2011 study in the Canadian Prairies (Zentner et al. 2011) revealed that organic farming, after a 5 to 7 year break even period, was more profitable than comparable conventional methods. However, the higher profitability was "highly dependent on the existence of organic price premiums" of at least 70%, because of lower yields and transition costs. Input costs for organic and traditional systems were broadly similar. Higher labour, machinery, and certification costs in organic farming system matched the savings from reduced pest management measures.

Modern Plant Breeding Impacts on Crop Production

Brookes and Barfoot (2014) found significant production and economic benefits for using biotech crops across 17 countries, including the U.S. and Canada. They estimated that biotech crops have added 122 million tons in maize production and 230 million in soybean production globally. In addition, their meta-analysis showed significant average farm income benefits across the world. Economic gains at the farm level of ~US$98.2 billion were generated globally by modern plant breeding technology during the sixteen year period 1996 to 2011, of which 51% were due to reduced production costs (less ploughing, fewer pesticide sprays and less labor) and 49% due to substantial yield gains of 328 million tons. The corresponding figures for 2011 alone was 78% of the total gain

In Canada, they estimated that the average farm income was 20% higher with biotech crops compared to non-biotech.

A 2014 report from the National Academy of Sciences in the U.S. (2014) noted broad economic and environmental benefits, including:

- Reduced tillage
- Reduced pesticide use
- Lower costs of production for farmers, and
- Greater on-farm safety

A November 2014 meta-analysis from Klumper (2014) found significant yield gains and pesticide reductions. Furthermore, he found that the economic benefits are greater for farmers in developing countries than in developed countries.

In a related paper, Adenle (2011) estimated that the farm income benefits for various biotech crops totalled $4.6 billion in the developed world and $4.7 billion in the developing world. In addition, biotech crops "contributed to reduced pesticide and fuel use, controlling water erosion, preserving soil structure, lowering tillage operations and green house gas emission" as well as fewer negative health impacts from reduced pesticide use.

It should be noted that most of the studies referenced above considered only GM/GE technologies, not the entire suite of modern plant breeding technologies, whereas this report includes all such technologies.

Related Sector Economic Impact Studies

In 2011, the CSLS conducted a study that looked at the very broad socioeconomic impacts of biotechnology as a whole for Canada. Looking at crop biotechnology specifically, they estimated that agriculture biotechnology producers in 2005 created $572 million in gross domestic product (GDP) measured in $2011, not counting the value-added of farms.

In 2014, the George Morris Centre estimated the contribution to GDP of the seed sector, including the sale and production of hybridized biotech seeds, at $826 million per year. This included supporting 7,422 jobs in Canada and over $200 million in wages and salaries. The GMC study used the 2010 Statistics Canada input-output model to estimate impacts of the seed sector.

Summary of Literature on Crop Yields

Twenty-three studies were retrieved from various peer reviewed journals that had yield data relevant to this study. The data in each study is in the following table. Each study is identified by lead author and coded as follows: CAD - Canadian study, NA - North American study, EU - European study, Other - Other/global metastudy, Bio - Biotech study (matched with relevant country code).

Table 33: Crop yields gains from plant science innovations (% yield gain)

	McCrae	Popp	Badgley	Gevrek	Gianessi	StatsCan 1	StatsCan 2	Scottfarm	Knutson	Pimentel	De Ponti	Nazarko	Oerke	Adenle	Palmer	Seufert	Entz	Cavigelli	CHC	BASF	Posner	Park	Klumper	Weighted Avg (pest control)	Weighted Avg (Modern plant breeding)
	CAD	NA	Other	NA	NA	CAD	CAD	CAD	NA	NA	Other	CAD	NA	NA-Bio	Other	Other	CAD	NA	CAD	NA-Bio	NA	NA-Bio	Bio		
Barley	10.0%		7.2%					23.1%			31.0%	25.4%	21.0%			30.0%	25.4%							21.2%	
Beans dry white	10.0%		18.4%		25.0%						12.0%													15.1%	
Beans coloured	10.0%		18.4%		25.0%						12.0%													15.1%	
Canary seed	10.0%		18.4%								19.0%													12.9%	
Canola	30.0%				45.0%						18.0%					12.0%	49.6%						17.7%	38.7%	17.7%
Chick peas	10.0%		18.4%								9.0%													11.2%	
Corn for grain	15.0%	37.0%	7.2%		20.0%				32.0%	30.7%	11.0%		33.0%	8.0%		18.0%		31.0%		17.8%	10.0%	14.5%	17.7%	22.8%	14.6%
Corn fodder	15.0%	37.0%	7.2%		20.0%				32.0%	30.7%	11.0%		33.0%	8.0%		18.0%		31.0%		17.8%	10.0%	14.5%	17.7%	22.8%	14.6%
Flaxseed	15.0%		7.2%								35.0%					12.0%	21.8%							18.3%	
Lentils	10.0%		18.4%								9.0%													11.2%	10.0%
Mustard seed	10.0%		7.2%																					9.4%	
Oats	5.0%		7.2%								15.0%	25.4%					27.1%							18.0%	
Peas dry	10.0%		18.4%		20.0%						15.0%						32.9%							20.4%	
Rye all	5.0%		7.2%								24.0%													8.5%	
Soybeans	15.0%	34.0%	18.4%		26.0%				37.0%	0.0%	8.0%		34.0%	0.0%		12.0%		23.3%			10.0%	3.0%	17.7%	23.9%	8.7%
Sugar beets	10.0%				29.0%								56.0%											26.3%	10.0%
Sunflower seed	10.0%				16.0%						23.0%					12.0%	45.8%							22.4%	10.0%
Wheat all	10.0%	22.0%	7.2%	17.0%	25.0%			23.1%	24.0%		27.0%	25.4%	21.0%			40.0%	23.3%	0.5%						20.0%	10.0%
Asparagus	25.0%		12.4%		55.0%	45.8%	55.0%				23.0%								55.0%					45.4%	
Beans	25.0%		12.4%		20.0%	70.5%	12.0%				23.0%								50.0%					37.7%	
Beets	25.0%		12.4%			45.5%	56.0%				23.0%								56.0%					45.0%	
Broccoli	25.0%		12.4%		14.0%	42.9%	44.0%				23.0%								100.0%					54.6%	
Brussels sprouts	25.0%		12.4%								23.0%								100.0%					66.8%	
Cabbage	25.0%		12.4%			45.4%	37.0%				23.0%								100.0%					57.5%	
Carrots	25.0%		12.4%		48.0%	13.5%	40.0%				11.0%								100.0%					51.4%	

	McCrae	Popp	Badgley	Gevrek	Gianessi	StatsCan 1	StatsCan 2	Scottfarm	Knutson	Pimentel	De Ponti	Nazarko	Oerke	Adenle	Palmer	Seufert	Entz	Cavigelli	CHC	BASF	Posner	Park	Klumper	Weighted Avg (pest control)	Weighted Avg (Modern plant breeding)
Cauliflower	25.0%		12.4%			47.6%	55.0%				23.0%				130.9%				100.0%					64.2%	
Celery	25.0%		12.4%		0.0%						23.0%								75.0%					52.5%	
Corn	25.0%	37.0%	12.4%		25.0%	-24.9%	-52.0%		32.0%		11.0%			8.0%				31.0%	100.0%	17.8%				27.6%	17.8%
Cucumbers	25.0%		12.4%		0.7%						23.0%								100.0%					58.5%	
Garlic	25.0%		12.4%			-11.5%	8.0%				23.0%								100.0%					41.9%	
Leeks	25.0%		12.4%								23.0%								67.0%					48.0%	
Lettuce	25.0%		12.4%		13.0%	65.3%	52.0%		67.0%		14.0%								100.0%					59.8%	
Dry onions	25.0%		12.4%		43.0%	57.2%	63.0%		64.0%		23.0%								75.0%					55.0%	
Other melons	25.0%		12.4%								23.0%								90.0%					61.1%	
Parsley	25.0%		12.4%								23.0%								6.0%					13.1%	
Parsnips	25.0%		12.4%								23.0%								100.0%					66.8%	
Peas	25.0%		12.4%								23.0%								85.0%					58.2%	
Pumpkins	25.0%		12.4%			51.5%	44.0%				23.0%								100.0%					59.9%	
Shallots	25.0%		12.4%								23.0%								80.0%					55.4%	
Spinach	25.0%		12.4%								23.0%								80.0%					55.4%	
Squash and zucchinis	25.0%		12.4%			31.7%	27.0%				23.0%								100.0%					53.2%	
Tomatoes	25.0%		12.4%		23.0%	23.6%	23.0%		77.0%		19.0%					21.0%			100.0%					49.6%	
Peppers	25.0%		12.4%								23.0%								100.0%					66.8%	
Radishes	25.0%		12.4%								23.0%								90.0%					61.1%	
Rhubarb	25.0%		12.4%								23.0%								44.0%					34.8%	
Rutabagas and turnips	25.0%		12.4%				6.0%				23.0%								100.0%					53.3%	
Watermelon	25.0%		12.4%								23.0%								80.0%					55.4%	
Apples	30.0%		4.5%		15.0%	15.4%	21.0%		100.0%		31.0%					3.0%			100.0%					49.4%	
Apricots	30.0%		4.5%								22.0%					3.0%			100.0%					63.3%	
Blueberries	30.0%		4.5%		67.0%	17.1%	-38.0%				22.0%					3.0%			62.0%					27.8%	
Cherries sour	30.0%		4.5%								22.0%					3.0%			75.0%					50.0%	

	McCrae	Popp	Badgley	Gevrek	Gianessi	StatsCan 1	StatsCan 2	Scottfarm	Knutson	Pimentel	De Ponti	Nazarko	Oerke	Adenle	Palmer	Seufert	Entz	Cavigelli	CHC	BASF	Posner	Park	Klumper	Weighted Avg (pest control)	Weighted Avg (Modern plant breeding)
Cherries sweet	30.0%		4.5%								22.0%					3.0%			75.0%					50.0%	
Cranberries	30.0%		4.5%		50.0%		-30.0%				22.0%					3.0%			70.0%					32.8%	
Grapes	30.0%		4.5%		1.0%				89.0%		22.0%					3.0%			89.0%					54.8%	
Nectarines	30.0%		4.5%				48.0%				22.0%					3.0%			74.0%					49.1%	
Peaches	30.0%		4.5%		11.0%	20.0%	30.0%		81.0%		22.0%					3.0%			70.0%					40.5%	
Pears	30.0%		4.5%			-27.5%	-22.0%				22.0%					3.0%			100.0%					32.7%	
Plums and prunes	30.0%		4.5%								22.0%					3.0%			100.0%					63.3%	
Raspberries	30.0%		4.5%		0.0%	-72.9%	9.0%				22.0%					3.0%			90.0%					26.7%	
Saskatoon berries	30.0%		4.5%								22.0%					3.0%								21.4%	
Strawberries	30.0%		4.5%			25.0%	9.0%				41.0%					3.0%			100.0%					48.0%	
Potatoes	25.0%	75.0%	10.9%		32.0%				57.0%		30.0%		50.0%		20.9%									39.3%	