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The Value of Plant Science Innovations to Canadians in 2020

Prepared for:

CropLife Canada

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Executive Summary

This report presents an update of the economic, environmental and social benefits of plant science innovations presented in our 2015 report, “The Value of Plant Science Innovations to Canadians.” Plant science innovations include pest control products and modern plant breeding that together further sustainable agriculture[1]. They create social, economic and environmental benefits through improved crop yields, quality and input efficiency. Plant science innovations play a significant role in diverse areas of the economy and other aspects of Canadians’ quality of life. They reduce food costs for Canadian consumers, help protect the environment in several ways, and support Canada’s trade balance.

Modern plant breeding and crop protection products have markedly improved yields and generated substantial revenues for Canada’s farmers. Plant science innovations have a significant economic footprint. They create numerous jobs directly for Canadians, supply downstream industries like animal production, milling, and biofuels and improve Canada’s overall economic productivity. Plant science innovations have supported local food production in Canada. They have established Canada as one of the world’s major exporters of agriculture products.

The Advisory Council on Economic Growth views agriculture as a vital industry to support economic growth. According to its report, Canada should target agricultural product exports to grow from 5.7% of total world agricultural trade to 8%. Similarly, Canada should double its share of agri-food exports. If Canada were to reach these targets by 2027, it would add $30 billion to the economy (Advisory Council on Economic Growth, 2017).

In a survey for Agriculture and Agrifood Canada (AAFC), four in five Canadians had a favourable impression of Canada's agriculture sector. Among the relatively small number with an unfavourable opinion, many believe that food prices are too high, that modern agriculture practice uses too many pesticides and harms the environment. On the contrary, the evidence shows that recent plant science innovations have enabled increased food production as farmland shrinks and cities expand, reduced the impact of agriculture on climate change, and improved the use of pesticides.

The following tables highlight the significant socioeconomic and environmental impacts of plant science innovations in Canada. A detailed discussion of the results and the methodology follows in the full report.

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[1] The UN defines sustainable as “meets the needs of the present without compromising the ability of future generations to meet their own needs.”

Summary of the economic benefits of plant science innovations

Stage in the Value Chain	Impact	Description	Results
Pre-farm	Pest control product manufacturing	Manufacturers of pest control products drive economic activity and employment before the products are used on farms.	Roughly $1 billion in domestic production per year supports $924 million in GDP, including $323 million in wages and nearly 5,400 jobs for Canadians.
	Modern plant breeding sales and manufacturing	Seed producers of plants with novel traits generate $2.2 billion in revenues per year.	The economic footprint of the production of seeds with novel traits supports $4 billion in economic activity and $2.1 billion in GDP. The industry generates more than 15,000 jobs and $540 million in wages for Canadian workers.
On-farm	Productivity and revenue impacts	The most important economic impact of plant science innovations is that they directly support on-farm productivity. Impacts are particularly significant for Canada's field crop industry concentrated in the Western provinces.	In total, Canada's crop production would be $9.2 billion lower if farmers grew the same crop mix without plant science innovations, including $7.7 billion less field crops, $1.0 billion less fruits and vegetables, and $460 million less potatoes. Tools registered under Canada's Minor Use Pesticide Program prevented between $653 and $998 million of crop losses, according to AAFC.
	Non-pecuniary benefits	GM crops allow for greater management flexibility. Farmers may use their time for other farming activities or find off-farm income.	Canadian farmers received an additional $127 million in non-pecuniary benefits from herbicide-tolerant (HT) soybean and insect-resistant (IR) corn.
	Farmland value	Since 2002, the value of Canada's farmland has more than tripled, a figure far higher than Canada's residential properties. Expected revenues are the primary driver of farmland value. Plant science innovations have certainly boosted on-farm revenues through higher yields.	It is challenging to make a precise estimate. Still, farmland values could be about 10-30% lower without plant science innovations due to lower revenues.

Post-farm	The economic impact of wholesale trade	Canada is a major global exporter of crops. Most of Canada's crop production is sold wholesale to manufacturers or exported before reaching consumers.	Based on a 16.7% wholesale margin, the value of wholesale trade related to additional farm output from plant science innovations added another $2.9 billion in economic activity and $1.8 billion in GDP, supporting nearly 14,700 jobs for Canadians.
	Supporting Canadian animal production and food manufacturing	Plant science innovations allow Canada's animal producers, biofuel producers and food manufacturers to be competitive using Canada's inputs.	Plant science innovations added $5.2 billion in "made in Canada" inputs to downstream industries. Animal production and grain milling are the most important downstream industries.
	Supplying feedstock for Canada's biofuel needs	Ethanol and biofuels are poised for growth in Canada due to an increased focus on climate change. Canada's field crops are vital inputs.	Canada's farmers would have supplied $200 million less feedstock for biofuels without plant science innovations – about 25% of all feedstock. Corn and wheat are the most commonly used field crops for biofuels in Canada.
	Strengthening Canada's trade position	A large portion of Canada's agricultural production is destined for foreign markets, particularly canola and other field crops, which benefit significantly from plant science innovations.	Canada's exports of agri-food products would have been 33% or $8.5 billion lower without the use of crop protection products, assuming farmers grew the same crop mix. Without plant science innovations, Canada's net agri-food trade balance could be as much as 72% lower.
Consumers	Consumers	Without plant science innovations, consumers would not have the same access to high quality and low priced food. Plant science innovations support food security overall in Canada. Canada's farmers would not be able to meet Canadians' food needs either now or in the future without plant science innovations.	Depending on the food product, prices would likely be anywhere from 14% to 144% (or even higher) for many food staples. In total, consumers would need to spend an estimated $29 to $75 billion more to buy exclusively organic products.

			The average household would spend between \$2,100 and \$5,500 more per year at grocery stores and restuarants, based on prevailing organic price premiums.
Economy-wide impacts	Overall economic labour productivity	Plant science innovations help make Canada's whole economy more productive by ensuring that labour and inputs are used as efficiently as possible.	After considering the dynamic and network effects of plant science innovations, Canada's economy would shrink \$3.3 billion without plant science innovations. In total, plant science innovations improve agricultural productivity by \$21,600 per FTE and Canada's overall labour productivity by an estimated \$195 per FTE.

Summary of environmental benefits of plant science innovations

Impact	**Description**	**Quantities/Data**
More efficient pesticide use	Crop protection products like glyphosate have reduced overall pesticide usage in many cases, particularly some older pesticides that were more harmful to human and environmental health. As a result, many Canadian farmers use much less active ingredient per hectare and per kilogram of production. The environmental impact of pesticides per hectare has also markedly declined due to biotechnology advances in plant science. In addition to advances in plant science innovations, new technologies like precision agriculture have allowed farmers to better target pesticide applications.	Ontario farmers in 2014 used just about 40% of the level of active ingredient per kilogram of production compared to 1983. Albertan farmers, by contrast, are using more because of the adoption of no-till agriculture. Glyphosate – the most common herbicide in Canada - is significantly less polluting than some of the older pesticides used. Overall, Brookes and Barfoot estimate that HT corn, soybeans and canola have reduced the environmental impact of pesticide use by as much as 35% in Canada.
More efficient land use	Canadian farmers produce much more without using more land, leaving untouched habitats for plants and animals and bolstering biodiversity. Reduced summer fallow has made	Without plant science innovations at current production levels, farmers would need 13.6 million hectares more of suitable land to produce the same

	Canada's agricultural land much more productive as well.	crop mix, an area larger than all of Canada's maritime provinces combined.
Reduced Green House Gas (GHG) emissions	No-till agriculture has allowed farmers to reduce their fuel use significantly, compared to conventional tilling methods. No-till methods also disturb the soil much less, allowing it to sequester more carbon.	Brookes and Barfoot estimate that switching to no-till and conservation till methods have reduced GHG emissions in Canada by 16 million tonnes between 1996 and 2018. Without plant science innovations, farmers in eastern provinces would need 2.1 million more hectares of land to grow the same crops as today. In total, this would add at least 130 to 169 million tonnes of GHGs to the atmosphere. In Saskatchewan, the net impact of agriculture on GHGs has fallen by 98% as farmers have adopted no-till and conservation till between 1996 and 2016.
Better soil quality	Plant science innovations allow farmers to use reduced tillage and summer fallow, dramatically reducing soil erosion. Tilling disrupts the soil structure and makes it more prone to erosion and run-off, releasing agricultural chemicals and nutrients.	Most of the Prairies – well over 80% of farmland - are now only at very low risk of soil erosion due to plant science innovations, a large improvement compared to 1981.
Higher biodiversity	Higher crop yields mean that more land is left in its natural state for plants and animals, even with a growing population. No-till agriculture has also improved agricultural land for birds, insects, small mammals and arthropods compared to tilled soil. No-till also reduces runoff into water habitats, further protecting aquatic organisms. Crop protection products may also be used to control invasive species when other prevention methods do not work. Pesticides are a necessary line of defence against invasive phragmites, sea lampreys and gypsy moths.	As much as 13.6 million hectares are maintained in a natural state due to plant science innovations, allowing for greater wildlife habitats No-till agriculture improves soil microbes and arthropods by up to 71%. It can also reduce pesticide runoff into sensitive ecosystems by more than 90%.

Plant Science

According to the Food and Agriculture Organization of the United Nations (FAO), plant breeding is the art and science of genetically improving plants for humankind's benefit. Many different techniques can be used, ranging from selecting plants with desirable characteristics for propagation to more complex molecular techniques. Plant breeding has a proven track record in increasing crop productivity. It is responsible for about 50% of crop productivity increase over the last century, while the remainder of the yield increase comes from better crop management (e.g., fertilization, irrigation, weeding). (FAO, 2020)

Plant science innovations encompass the technological improvements that make agricultural systems more productive and ensure sustainable development. Plant science is used to develop new techniques or technologies that protect crops or improve their quality. Broadly speaking, plant science innovations fall into three categories: traditional plant breeding, modern plant breeding, and crop protection products.

Traditional plant breeding

Plant breeding has been a fixture of agricultural practices for many millennia. For example, corn was the product of thousands of years of selection from the original breed, teosinte, which hardly resembles modern corn as we know it.

Plant breeders have used "traditional plant 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, and other characteristics for production in particular geographies and climatic zones. Traditional plant breeding involves selecting specific plants or varieties of a species and breeding them to enhance their expression of specific traits or genes, such as crossing a plant with high yields and a plant with increased drought resistance to create a new variety with both high yields and high drought resistance. Plant breeders may use selective pollination, cloning, or other techniques to express the desired traits.

Norman Borlaug, Nobel Prize Peace Prize winner and agronomist, crossbred varieties of dwarf wheat to make them more disease resistant and better suited to sub-tropical climates (Hedden, 2003). He is often credited with saving more than a billion lives. In Canada, Dr. William Saunders used selective breeding in 1904 to produce Marquis Wheat – a cross created from Hard Red Calcutta and Red Fife varieties – with higher yields and a shorter maturation.

Traditional plant breeding has several challenges, despite its many successes. First, many genetic crosses and selection cycles are required to obtain or reinforce the particular trait or gene combination, with no guarantee of success. From here, undesirable genes may be shifted along with the desirable traits. While one desirable gene is gained, another is lost because both parents' genes are mixed and assorted randomly in the offspring.

Modern plant breeding

Traditional plant breeding is still used today. However, agricultural scientists have adopted more advanced techniques for modern plant gene editing to target specific genes and desirable traits. Current genetic modification allows scientists to modify a plant's genetic makeup selectively, making the process more precise and efficient. Plant breeding is an ever-evolving continuum of tools that strive to make the process of discovering and incorporating desirable traits into plants more accurately and efficiently. Modern plant breeding is a multi-disciplinary process that is often aided by molecular tools and involves conventional breeding techniques, bioinformatics, molecular biology and recombinant DNA (rDNA) driven genetics.

Modern plant breeding techniques include:

- Tissue culture and micro-propagation
- Embryo rescue
- Molecular breeding, or marker and genomics assisted selection
- Molecular diagnostic tools
- Mutagenesis, a process by which plant breeders alter a plant's genes by using chemicals or radiation, followed by selecting the desired variants to introduce into conventional breeding programs to create new varieties.

A significant innovation in the modern plant breeding era was the rise of rDNA-driven genetic engineering (GE), living modified organisms (LMOs) or the genetic modification (GM) of crops (also known as GMOs for genetically modified organisms). This technique allowed plant breeding to incorporate beneficial traits from outside the species, creating transgenic plants.

More recently, a group of tools referred to as genome editing have come to the forefront, allowing for even more targeted and precise edits to plants. Clustered regularly interspaced short palindromic repeats (CRISPR) has become a principal method for plant gene editing. It was first used in plant breeding in 2013 (Wang, Zhang, & Zhu, 2019). CRISPR-Cas genome editing can reduce the time to replicate a new trait in an existing breed from 8-10 years with crossbreeding or mutagenesis to only 4-6 years (Chen, Wang, Zhang, Zhang, & Gao, 2019).

A recent European Union (EU) study found that plant breeding contributed about 74 percent to total productivity growth in agriculture since the turn of the millennium, equal to an increase in yields by 1.24% per annum (Noleppa, 2016).

In Canada, farmers grow genetically-modified corn, canola, soy and sugar beets. For all four of these field crops, 92% of all acres planted in Canada are now genetically modified varieties that are herbicide-tolerant.

Canadian farmers also have access to several crops from seed mutagenesis, including oats, barley, flax, and beans, that exhibit traits like faster maturity, higher yields, improved disease resistance, or herbicide tolerance.

Crop protection products

Crop protection products include any means that farmers use to protect crops from pests, such as herbicides, insecticides, fungicides, antimicrobials and vertebrate controls. Crop protection products are an integral part of Canada's agriculture value chain. Nearly all Canadian farmers reported some use of crop protection products in 2017 (see Table 1). Synthetic crop protection products such as glyphosate - a broadleaf herbicide - are the most applied in Canada (see Pest Management Regulatory Agency (PMRA) summary in Annex I). Farmers purchased over 50 million kilograms of active ingredient in 2017 (Health Canada, 2017).

Organic farmers in Canada likewise may also use various natural crop protection products - many of which are produced by CropLife members - despite many consumers' perception that organic means pesticide-free[2]. In total, the Government of Canada General Standards Board has approved 65 different crop production aids and materials suitable for organic crops. These compounds include, for example, plant-derived insecticides such as pyrethrum, lime sulphur – to protect fruit trees and mineral oil - used as an insecticide (Canadian General Standards Board, 2018).

Mineral oil is the most commonly purchased crop protection product in Canada that is suitable for organic farming. Farmers applied more than 1 million kgs in 2017. Organic crop protection products continue to be monitored for their effects on the environment. They must follow the same regulations as synthetic crop protection products in Canada. They may also have damaging effects on the environment. In Europe, higher concentrations of copper in soil have been found in olive plantations and vineyards because of the use of copper sulphate fungicides(EIP-AGRI, 2019). Pyrethroid pesticides are similarly potentially toxic in high concentrations in the environment(Tang et al., 2018).

Table 1: Percent of farms reporting pesticide use in 2017 (%)

Use of pesticides in field crops by province					
Geography	Herbicide	Insecticide	Fungicide	Biopesticide	Other pesticides
Canada	93	26	38	1	1
Quebec	94	13	19	n.a.	n.a.
Ontario	90	35	38	1	2
Manitoba	98	26	61	n.a.	n.a.
Saskatchewan	94	26	37	1	n.a.
Alberta	92	20	42	n.a.	2
Use of pesticides in fruits, vegetables, berries and nuts production by province					
Canada	76	68	70	9	7

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[2] According to Campbell et al., one in four Canadians believe that organic produce uses no natural pesticides and 52% believe that organic produce has no pesticide residues. In fact, pesticide use in organic agriculture is common and residues are similar between both organic and non-organic produce(Campbell, Mhlanga, & Lesschaeve, 2013).

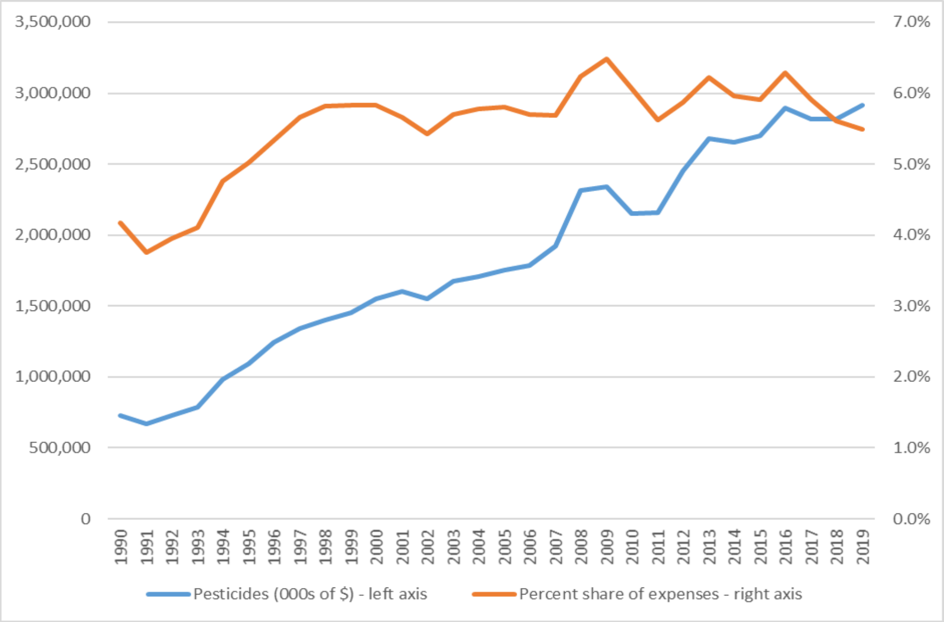
Prince Edward Island	89	97	86	n.a.	n.a.
Nova Scotia	63	65	62	6	7
New Brunswick	72	73	68	9	n.a.
Quebec	77	63	59	16	6
Ontario	84	78	76	6	8
Manitoba	93	87	96	n.a.	n.a.
Alberta	98	55	49	n.a.	n.a.
British Columbia	69	60	72	10	10

Source: Statistics Canada, Farm Management Survey. Note that data is not available for all provinces due to low data quality, few active farms or privacy issues. Other pesticides may include nematicides, rodenticides, or bactericides.

For field crops, fruits and vegetables in Canada, herbicides are the most commonly applied crop protection product. Fruit and vegetable farmers also use fungicides and insecticides significantly more often than field crop farmers to protect delicate produce.

Revenues of pesticides have steadily increased in Canada. In 2019, Canadian farmers purchased close to $3 billion in pesticides. Although pesticide sales have nearly quintupled since 1990, they remained a steady share of input costs, averaging about 6% of total on-farm input costs since 1997, when many GM crops first became commercially available[3]. Although pesticides are only a fraction of Canadian farmers' input costs, they play a vital role in Canada’s $30 billion crop production industry.

Figure 1: Pesticide sales to farmers, 1990 to 2019



Source: Statistics Canada, Table 32-10-0136-01

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[3] Fertilizers and seeds have had slightly larger increases in their share of inputs.

The Economic Footprint of Plant Science Innovations in Canada

Economic context of agriculture in 2020

A trifecta of COVID19, ongoing trade disputes and weak oil prices in early 2020 have driven Canada’s economy into its deepest recession since the Great Depression. Second-quarter GDP plummeted a record-breaking 38.7% due to extensive COVID19 closures and falling merchandise trade. The Government of Canada expects the economy to contract 6.8% this year before mostly recovering in 2021 as vaccines become readily available. For the fiscal year 2020-21, the Canadian government anticipates that it will post an eye-watering deficit. The federal deficit will soar from 19.8 billion in 2018-19 to at least $380 billion in 2020-21.

In 2020, the COVID19 crisis complicated matters further for farmers as borders closed to travel and, for some time, the export of goods. Countries rapidly shifted trade policy to restrict exports of needed products. By summer, though, trade restrictions began to lift, and many of Canada’s agricultural exports are at or above their 2019 level.

One of the lone bright spots in Canada’s economy in 2020 was crop production, which was relatively unaffected by shutdowns in the spring. By October 2020, the agriculture industry had grown 1.5% year-over-year. In 2020, pulse, oat and wheat production rose significantly, according to the AAFC. Soybeans made a modest recovery after trade disputes reduced output in 2019, although production is still below 2018 levels.

The notable exception is fruits and vegetables. Farmers planted fewer acres this year and have had less access to temporary foreign workers, so fruit and vegetable production has been down overall.

The agriculture and agri-food industry has immense potential as well. Canada’s Advisory Council on Economic Growth believes that there is plenty of room to grow. The world population is set to hit 8 billion people by 2024, and Canada could play a key role in supplying food to the rest of the world. Canada was already the eighth largest agricultural exporter in the world in 2018. Still, Canada has seen its share of global agricultural exports slip from a high of 6.4% in 2000 to 3.4% in 2018[4]. In its 2017 report, the Advisory Council recommended that the Government of Canada support agri-food sector growth. According to the report, Canada should target agricultural product exports to to 8%. Similarly, Canada should double its share of agri-food exports in 2017. If Canada were to reach these targets by 2027, it would add $30 billion to the economy (Advisory Council on Economic Growth, 2017).

The Advisory Council recommended that Canada establish preferential trade agreements with key countries, notably India, China, and Japan. Unfortunately, trade disputes have stymied

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[4] Data from the WITS database in USD.

agricultural exports to some of these same markets. Canada’s Western Canadian Wheat Growers estimated that trade disputes and non-tariff barriers to trade cost the agriculture industry $3.7 billion (Stephenson, 2019).

As we will see in the sections below, plant science innovations have played a key role in Canada’s economy, trade, and improving Canada’s productivity. New crop protection products and higher-yielding varieties will play a role in meeting an ambitious goal for growth.

On-Farm Revenue Impacts of Plant Science Innovations

Methodology

In 2015, RIAS Inc used a meta-analysis of 22 different studies comparing on-farm yield impacts between different production systems to estimate the total yield impacts across all major field crops, fruits and vegetables in Canada (RIAS Inc., 2015).

In 2020, we estimated the difference in yields between the current situation and the counterfactual by crop and type of technology based on the original 22 studies and an additional seven since the 2015 report for a total of 29 studies and meta-analyses. This academic review has been supplemented with input from experts from the horticulture industry.

Of course, not every study compares the same farming system, period or location. Therefore, estimates from each study are weighted according to how closely they may reflect Canada’s crop production sector's current situation. Older reviews and analyses of farming practices outside of North America were given less weight.

Of the 29 studies, five directly measure the impacts of only pesticide use on yields and 19 compared the differences between organic and conventional farming.[5] Four contrasted the difference between using GM varieties to non-GM. One study was based on expert input from Canada’s Horticultural Council.

Using organic and conventional farming studies to estimate the impacts will overall underestimate the effect of crop protection products on yields. Organic farm production, mainly fruit and vegetable production, uses many crop protection products. As expected, the studies that focus only on crop protection products estimate far higher yield impacts than studies that compare merely conventional and organic production.

On the other hand, some of the difference in yields between organic and conventional production is explained by different fertilizers and soil nitrogen. Only one study controlled for fertilizer use and soil nitrogen. However, organic production has access to many effective, naturally derived fertilizers. Also, it employs different crop rotation practices to support soil nitrogen levels that

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[5] Conventional farming generally refers to any agricultural system in which synthetic chemical inputs are used. However, organic farming does not mean “chemical-free”, or “pesticide-free”. While organic farming practices have greatly advanced the use of non-chemical means to control pests, these non-chemical methods do not always provide enough protection, and organic pesticides must be used.

would mitigate the difference from this input. According to Seufert, organic systems are more nitrogen-limited and require a higher fertilizer input than conventional farming(Seufert, Ramankutty, & Foley, 2012). Controlling for equal soil nitrogen levels increases the difference between organic and conventional farming.

Some studies are not comparing the same varieties or locations. Different locations may have different yields, even when controlling for inputs and farm systems. The Statistics Canada studies compare conventional and organic farms across Canada in different regions and, possibly, with different germplasms. These studies tend to find the highest variance in yields among different crops, vegetables and fruit.

Finally, for the analysis, we have added the increase in yield from modern plant breeding to the impact of crop production products. The studies on modern plant breeding yields typically compared yields attributable to both modern plant breeding and use of crop protection products. In fact, crops with modern plant breeding often use fewer pesticides overall.

Results

In total, Canada's farmers would have lost an estimated $9.2 billion or 32.8% of all crop sales had they not been able to use crop protection products and modern plant breeding in 2019 and made no changes to the seeded acreages. Since the 2015 report, crop protection products and plant science innovations have become even more critical to on-farm productivity. The revenue impact of plant science innovations has risen around $1 billion from 2015, indicating that farmers have grown relatively more crops that plant science innovations beneficially impact.

Field Crops

Field crops are the largest subsector of Canada's crop production industry and therefore benefit the most from plant science innovations. In total, if Canadian farmers attempted to grow the same field crops on identical acreages without plant science innovations, Canada's field crop production would be $7.7 billion or 31.7% lower. Canola revenues – the most extensive field crop in Canada by revenue and itself a product of selective breeding – would be $4.0 billion lower without plant science innovations.

Table 2: Farmgate revenue impacts of plant science innovations for field crops in Canada

	Total Farmgate Value ($000s)	Average Production (tonnes)	Weighted % Yield Loss without Plant Science Innovations	Incremental Impact on Farmgate Value ($000s)
Canola (CP)	$8,613,028	18,648,800	35%	$2,509,101
Canola (MPB)			18%	$1,464,783
Wheat (CP)	$6,730,817	32,347,800	21%	$1,391,440
Wheat (MPB)			10%	$22,362
Corn (CP)	$2,212,671	25,801,400	25%	$456,641
Corn (MPB)			18%	$385,532

Soybeans (CP)	$2,515,448	6,045,100	26%	$616,372
Soybeans (MPB)			9%	$185,412
Barley	$949,391	10,382,600	18%	$174,310
Peas dry	$890,017	4,236,500	16%	$140,466
Lentils (CP)	$867,159	2,166,900	8%	$66,298
Lentils (MPB)			10%	$72,214
Oats	$634,775	4,237,300	15%	$95,229
Flaxseed	$215,170	339,300	15%	$31,446
Beans	$218,672	316,800	14%	$29,827
Sugar beets (CP)	$53,866	903,800	25%	$12,282
Sugar beets (MPB)			10%	$5,387
Canary seed	$89,173	147,500	10%	$8,507
Chick peas	$92,818	251,500	8%	$7,741
Mustard seed	$79,948	134,600	7%	$5,792
Sunflower (CP)	$16,338	62,900	25%	$4,020
Sunflower (MPB)			10%	$355
Rye all	$52,812	333,400	7%	$3,655
Total	**$24,083,005**	**105,825,300**	**31.7%**	**$7,689,170**

Notes: CP = crop protection, MPB = modern plant breeding.
Source: Statistics Canada, author's calculations. A full table of the *Weighted % Yield Loss without Plant Science Innovations* is available in the Annex IV. Note that some columns do not add to the national total due to missing or suppressed provincial data.

Fruit and vegetables

In Canada, modern plant breeding techniques have attracted relatively little investment in fruits and vegetables, except for the approval of non-browning apples in 2015 and small acreages of late-blight resistant potatoes. Canada's fruits and vegetables – both organic and conventional - rely heavily on crop protection products.

Crop protection products are crucial for protecting fruit and vegetable yields. Many fruits and vegetables would not be profitable without their use, so Canadian consumers would be obliged to import them from abroad at a higher cost. Crop yield losses for some fruits and vegetables would likely exceed 50% without crop protection products.

Overall, in 2019, Canada's fruit farmers would have lost an estimated $464 million of revenues andvegetable farmers would have lost $542 million without crop protection products. Additionally, Canada's potato production revenues would be more than $460 million lower without crop protection products[6]. Grapes, apples, blueberries, and strawberries would be the

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[6] Varieties of GM potatoes are approved for production and sale in Canada. However, only a small acreage is grown commercially for U.S. export, so they are not included in this analysis.

most affected fruit crops. Carrots, onions, tomatoes and lettuce would be the most affected vegetables.

What was not captured in the program review or our previous analysis is that many fruits, vegetables, and field crops would not be economical for farmers to produce in Canada without using crop protection products. For example, all of Canada's sugar beet production relies on biotechnology; without it, it is unlikely that any sugar beets would be grown at all. Similarly, many fruits and vegetables would not be economical to produce without fungicides and other crop protection products. Local products would lose out to international competitors with better growing conditions and access to crop protection products.

Table 3: Farmgate revenue impacts of plant science innovations for fruits in Canada

	Total Farmgate Value ($000s)	Average Production (tonnes)	Weighted % Yield Loss without Plant Science Innovations	Incremental Impact on Farmgate Value ($000s)
Grapes	$202,371	115,498	59.3%	$119,929
Apples	$240,041	377,929	45.7%	$109,781
Blueberries	$270,692	176,127	23.8%	$64,348
Strawberries	$123,678	27,252	39.9%	$49,371
Cherries sweet	$89,298	22,079	50.2%	$44,860
Cranberries	$135,411	172,440	29.6%	$40,109
Peaches	$35,797	22,862	39.0%	$13,955
Raspberries	$32,116	9,145	24.2%	$7,760
Plums and prunes	$7,789	3,642	55.5%	$4,323
Pears	$10,699	9,668	31.1%	$3,329
Nectarines	$7,222	3,435	44.3%	$3,202
Cherries sour	$4,290	4,591	50.2%	$2,155
Apricots	$2,003	982	50.8%	$1,017
Total	**$1,161,407**	**945,650**	**40.0%**	**$464,141**

Source: Statistics Canada, author's calculations. A full table of the *Weighted % Yield Loss without Plant Science Innovations* is available in the Annex IV. Note that some columns do not add to the national total due to missing or suppressed provincial data.

Table 4: Farmgate revenue impacts of plant science innovations for vegetables in Canada

	Total Farmgate Value ($000s)	Average Production (tonnes)	Weighted % Yield Loss without Plant Science Innovations	Incremental Impact on Farmgate Value ($000s)
Carrots	$133,309	360,195	41.7%	$55,609
Dry onions	$110,120	250,847	43.9%	$48,388
Tomatoes	$108,967	490,286	42.8%	$46,648
Lettuce	$82,222	84,902	51.4%	$42,231
Cabbage	$88,225	163,881	46.9%	$41,376
Peppers	$72,127	63,438	52.7%	$38,043
Broccoli	$78,124	42,313	48.6%	$37,947

Corn	$73,135	189,554	41.4%	$30,243
Cucumbers	$35,574	59,612	60.5%	$21,530
Cauliflower	$36,670	31,598	45.9%	$16,818
Squash and zucchinis	$42,164	53,877	39.5%	$16,643
Asparagus	$44,022	10,235	37.6%	$16,531
Shallots	$35,073	16,269	43.9%	$15,381
Pumpkins	$32,101	75,855	44.4%	$14,246
Rutabagas and turnips	$30,897	44,613	40.6%	$12,531
Beans	$38,279	61,116	32.6%	$12,497
Peas	$23,411	47,775	51.6%	$12,088
Celery	$19,896	32,441	47.0%	$9,344
Radishes	$18,319	15,618	48.3%	$8,848
Brussels sprouts	$13,574	6,757	52.7%	$7,160
Watermelon	$13,649	32,942	50.7%	$6,926
Beets	$18,959	52,222	33.4%	$6,342
Spinach	$10,355	4,607	49.4%	$5,117
Garlic	$14,245	1,248	34.5%	$4,916
Leeks	$12,316	6,413	38.1%	$4,690
Parsnips	$8,386	6,264	52.7%	$4,423
Other melons	$8,724	12,472	48.3%	$4,214
Parsley	$4,971	1,898	18.3%	$910
Rhubarb	$2,810	1,656	27.9%	$783
Total	**$1,210,624**	**2,220,904**	**44.8%**	**$542,421**

Source: Statistics Canada, author's calculations. A full table of the *Weighted % Yield Loss without Plant Science Innovations* is available in the Annex IV. Note that some columns do not add to the national total due to missing or suppressed provincial data.

Agricultural impact by province

Canada's Western provinces have benefited the most from plant science innovations, particularly Saskatchewan, where farmers planted over 40% of Canada's acres of canola in 2019. Nearly two-thirds of all of the revenue benefits to fruit and vegetable production are in Quebec and Ontario. However, British Columbia benefits more in fruit production.

Table 5: Farmgate revenue impacts of plants science innovations by province, 000s of dollars

	Crops	Fruit	Vegetables	Potatoes	Provincial Total
Newfoundland and Labrador	$0	$244	$1,408	$464	**$2,115**
Prince Edward Island	$10,840	$2,697	$4,196	$86,060	**$103,792**
Nova Scotia	$6,257	$19,835	$13,840	$2,376	**$42,307**
New Brunswick	$6,803	$10,999	$3,206	$59,460	**$80,468**
Quebec	$424,795	$100,990	$187,642	$63,041	**$776,468**
Ontario	$1,065,273	$146,684	$232,552	$38,790	**$1,483,299**
Manitoba	$1,112,364	$779	$13,957	$83,620	**$1,210,720**
Saskatchewan	$3,316,675	$479	$2,684	$12,209	**$3,332,048**

Alberta	$1,717,920	$829	$18,623	$91,214	**$1,828,585**
British Columbia	$28,244	$179,530	$40,109	$22,421	**$270,304**
Total	**$7,689,170**	**$464,141**	**$542,421**	**$459,654**	**$9,155,386**

Source: Statistics Canada, author's calculations. A full table of the *Weighted % Yield Loss without Plant Science Innovations* is available in the Annex IV. Note that some columns do not add to the national total due to missing or suppressed provincial data.

The Economic Impact of Canada's Minor Use Pesticides Program

Numerous minor use pest control products have been approved in recent years under the AAFC Pest Management Centre's Minor Use Program. The program aims to ensure that Canada's farmers have access to new and innovative crop protection methods.

This program's economic impacts are substantial for minor-use growers. The Minor Use Program has been a boon for Canada's horticulture sector and widely regarded as a successful government intervention. In 2019, AAFC reviewed the program, which started in 2003, and stated that:

- Minor crop production is an important and growing sector. The program fills an ongoing need for grower access to minor uses of pest control products to support the competitiveness and environmental sustainability of this sector. This need is not addressed by any other stakeholders.
- The program is aligned with federal government priorities and departmental strategic outcomes. The program is consistent with federal responsibilities for the regulation of pesticides and a national perspective supports Canada's participation in international trade and regulatory harmonization activities.
- New pesticides for minor uses are enabling growers to adapt to changes in the technological, regulatory, and trade environment. The program's participation in international fora and agreements supports harmonization of regulations with other countries. This activity is not clearly articulated in the program's logic model.
- Economic analyses indicate that the incremental economic impact of the program is substantial. Since its inception, the program is estimated to have contributed to the prevention of crop losses in the range of $653-million to $998-million. This is estimated to be a return of $42 of net benefits for every $1 invested by the government.
- The program is well-regarded with a sound design and clear and adequate governance; no significant changes are required to the program's key components. (Government of Canada: Agriculture and Agri-Food Canada, 2019)

Other on-farm benefits

Beyond the direct impact of plant science innovations on-farm revenues from higher production, farmers also receive indirect economic and efficiency benefits.

Barfoot and Brookes note several non-pecuniary benefits to farmers of insect-resistant, *bacillus thuringiensis* (IR-*Bt*) and herbicide-tolerant(HT) crops in the U.S. For example, GM crops allow for greater management flexibility. Farmers may use their time for other farming activities or find off-farm income. Conservation till practices have also saved farmers significant machinery, fuel and labour costs. According to Brookes and Barfoot, Marra and Piggot found that IR-*Bt* corn creates non-pecuniary benefits of $7.41 U.S. per hectare, and HT soybean produced $12 U.S. per hectare (Brookes & Barfoot, 2020).

Based on the current acreages of HT soybean and IR-*Bt* corn in Canada and these U.S. results, Canadian farmers receive an additional $128 million in non-pecuniary benefits from those two crops alone ($123 million for IR-*Bt* corn and $5 million for HT soybeans).

Pre-farm Revenue Impacts of Plant Science Innovations

The economic footprint of plant science innovations extends to the producers and suppliers of plant innovations. The two main parts of the value chain are the market for certified seeds in Canada, which helps guarantee genetic purity and genetic quality of seeds in Canada, and the manufacture, production and distribution of pest control products themselves in Canada.

Seed Sales from Modern Plant Breeding

Certified seed is seed produced under stringent standards to protect varietal purity so that seeds maintain beneficial genetic traits year after year. The Canadian Food Inspection Agency (CFIA) manages the program in Canada. The Seed Program Quality System Procedure (QSP) from the CFIA outlines the pedigreed seed crop inspection processes in Canada.

In 2018, JRG Consulting Group and SJT Solutions prepared a new economic impact study for the Seed Synergy Collaboration Group on the value of Canada’s certified seed on the Canadian economy. The authors estimated that seed growing as a whole generated $3.2 billion in revenues in 2017 and supported more than $6 billion in economic activity. Overall, Canadian farmers spent $2.6 billion on Canadian grown, certified seed, and they exported a further $500 million (JRG Consulting Group, 2018).

According to the Canadian Seed Growers Association, Certified Seed growing areas have remained stable near 1.3 million acres or 520,000 hectares or 4.3% of the total field crop acreage in Canada as of 2019 (Canadian Seed Growers’ Association, 2020).

We have scaled our estimates based on the share of domestically produced seeds from modern plant breeding, using the seeded acreage for the crops employing modern plant breeding technology. Modern plant breeding technologies resulted in an estimated $2.2 billion in domestic seed sales, including exports.

Table 6: Modern plant breeding seeded acreage and estimated revenues by field crop, 2018

Crop	Seeded Acreage 2019 (hectares)	Estimated commercial seed sales ($ millions)	Trade adjustment ($ millions)	% of the crop planted with modern breeding technology	Domestic modern plant breeding seed sales ($ millions)
Canola (rapeseed)	8,319,200	$1,382.0	-$37.9	95% (biotech)	$1,276.9
Corn for grain	1,451,200	$424.6	-$108.4	93% (biotech)	$294.1

Lentils	1,488,600	$88.4	$137.9	82% (mutagenesis)	$185.0
Soybeans	2,270,500	$487.2	$39.3	83% (biotech)	$437.0
Sugar beets[7]	12,400	$0.7	-$10.4	100% (biotech)	-$9.7
Sunflower seed	28,800	$3.0	-$5.3	20% (mutagenesis)	-$0.5
Wheat, all excluding durum wheat	7,753,800	$301.3	$0.2	3% (mutagenesis)	$9.0
Wheat, durum	1,901,700	$99.6	$0.2	3%	$3.0
Total	23,226,200	$2,786.8			$2,194.9

Source: Statistics Canada, JRG Consulting Group, and author's own calculations

The industry generated $4.2 billion in economic output and $2.1 billion in GDP in Canada in 2019. The industry supported more than 14,900 jobs and $537 million in incomes, including indirect and induced effects.

Table 7: Economic impact of the modern plant breeding seed industry

	Crop production multipliers	Economic impact of modern plant breeding seed industry ($ millions, Jobs = # of FTEs)
Direct impact		
Jobs	3.04	6,665
Output	1	$2,194.85
GDP	0.47	$1,035.97
Wages and salaries	0.07	$147.05
Indirect and induced impacts		
Jobs	3.76	8,247
Output	0.88	$1,924.88
GDP	0.46	$1,016.22
Wages and salaries	0.18	$390.68
Total impacts		
Jobs	6.79	14,912
Output	1.88	$4,119.73
GDP	0.94	$2,052.19
Wages and salaries	0.25	$537.74

Source: Statistics Canada National Multipliers 2016, author's own calculations.

Pest Control Product Manufacturing in Canada

Unfortunately, Statistics Canada and Innovation, Science and Economic Development Canada (ISED – formerly Industry Canada) no longer publish pesticide manufacturing data for Canada (NAICS 325320). However, in 2019, pesticide farm sales were $2.9 billion, imports were $1.8

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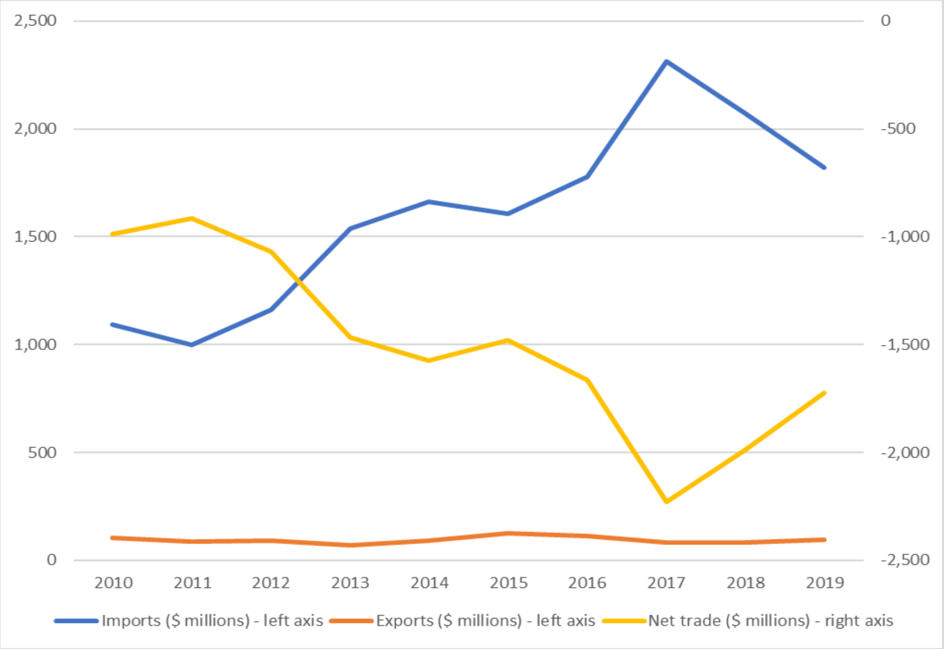
[7] Imports of sugar beet seeds and sunflower seeds exceeded revenues, as a result they have a small net negative economic impact.

billion, and exports were $94 million, implying that domestic manufacturing had a value of approximately $1 billion.

Information from IBIS World and CropLife Canada confirmed that pest control product manufacturing sales in Canada were $1 billion in 2019 (IBIS World, 2020).

Although industry-wide figures must be approximated, ISED reported 49 pesticides and other chemical manufacturers in Canada (including both agricultural and household chemicals). Thirty-five of these firms were SMEs with average annual revenues of $695,000.

Figure 2: Canada imports and exports of pesticides, 2010 to 2019



Source: ISED Trade Data

Based on an industry total of $1 billion in revenues, we have applied the 2016 Canada multipliers for the “Pesticide, fertilizer and other agricultural chemical manufacturing” industry from Statistics Canada, most closely representing the input-output structure of the industry. In total, the pesticide manufacturing industry supported an anticipated $924 million in GDP, $323 million in wages and nearly 5,400 jobs.

Table 8: Economic impacts of pesticide manufacturing in Canada

	Pesticide, fertilizer and other agricultural chemical manufacturing multipliers	Economic impact ($ millions, Jobs = # of FTEs)
Direct		
Jobs	1.164	1,164
Output	1	$1,000
GDP	0.358	$358

Wages and salaries	0.092	$92
Indirect and Induced		
Jobs	4.286	4,286
Output	1.043	$1,043
GDP	0.566	$566
Wages and salaries	0.231	$231
Total		
Jobs	5.449	5,449
Output	2.043	$2,043
GDP	0.924	$924
Wages and salaries	0.323	$323

Source: Statistics Canada National Multipliers 2016, author's own calculations.

Post-farm Revenue Impacts of Plant Science Innovations

Plant science innovations also ensure that Canadian businesses can access the raw products they need for manufacturing or export. After Canada's field crops, fruits and vegetables leave the farm, they are most likely sold wholesale first before they are used as an input in Canada's animal production industry, processed or exported.

Just over twelve percent of farmers (or around 24,000 farms) in Canada also engage in direct sales to consumers. However, this makes up less than five percent of farm revenues overall (Statistics Canada, 2017).

Canada's agricultural crop output was primarily processed into animal feed or milled. However, ethanol production has increasingly become a critical downstream industry for Canada's field crop farmers. A significant portion of fruits and vegetables grown in Canada were preserved or processed for later consumption. However, the Advisory Council for Economic Growth noted that, relative to other countries, much of Canada's agricultural production is not locally processed. If Canada's Government were to introduce measures to support downstream agricultural industries, plant science innovations' post-farm economic footprint would grow.

Wholesale Trade

As in the previous 2015 study, Statistics Canada farming wholesale and distribution multipliers are based on the revenues net of the cost of goods sold. In this report, we have also made an adjustment of 4.3% for direct-to-consumer sales that will not have generated any wholesale margins. Wholesale margins in 2018 were 16.7%, a slight decline from 17% used in 2015.

Overall, wholesale trade of plant science innovations supported $2.9 billion in economic activity in Canada and $1.8 billion in GDP (about half in the form of wholesaling margins) and 14,700 jobs.

Table 9: Economic impact of wholesale trade of additional farm revenues

	Farm wholesale multipliers	Crop protection economic impact (000s of dollars, Jobs = # of FTEs	Modern plant breeding economic impact (000s of dollars, Jobs = # of FTEs
Direct			
Output	1.00	$1,172,230	$356,719
GDP	0.60	$702,166	$213,675
Wages and salaries	0.22	$259,063	$127,991
Jobs	4.97	5,470	1,665
Indirect and Induced			
Output	0.93	$1,086,657	$330,679
GDP	0.56	$659,966	$198,077
Wages and salaries	0.24	$281,335	$118,648
Jobs	5.26	5,797	1,764
Total			
Output	1.93	$2,258,888	$687,398
GDP	1.16	$1,362,132	$411,751
Wages and salaries	0.46	$540,398	$246,639
Jobs	10.23	11,267	3,429

Source: Statistics Canada National Multipliers 2016, author's own calculations.

Key downstream industries

Beyond the on-farm impacts, Canada's downstream food manufacturing, basic chemical manufacturing (mostly the manufacture of ethanol for use as a fuel additive), and animal food also use a significant share of the output from plant science innovations. In total, in 2015, Canada's crop production industry supplied over $16.6 billion of products to Canada's business to add additional economic value. The bulk of the amount produced went to Canada's grain and oilseed milling and animal production sectors, each receiving over $5.0 billion.

Table 10: Key downstream industries for the crop production sector in Canada, 2015

Rank		Value of industry agr. input in 2015 (000s of dollars)	Estimated share from plant science innovations	Estimated value of input from plant science innovations (000s of dollars)
1	**Animal production (except aquaculture)**	$5,529,171	31.4%	$1,736,160
2	**Grain and oilseed milling**	$5,388,636	31.4%	$1,692,032
3	**Animal food manufacturing**	$1,427,310	31.4%	$448,175

4	**Basic chemical manufacturing**	$621,273	31.4%	$195,080
5	**Fruit and vegetable preserving and specialty food manufacturing**	$428,452	31.4%	$134,534
6	**Other food manufacturing**	$342,834	42.4%	$145,362
7	**Food services and drinking places**	$227,053	42.4%	$96,270
8	**Greenhouse, nursery and floriculture production**	$75,803	42.4%	$32,141
9	**Sugar and confectionery product manufacturing**	$64,041	40.0%	$25,616
10	**Wineries and distilleries**	$50,389	40.0%	$20,156

Source: Statistics Canada National Multipliers 2016, author's own calculations.

Out of the $16.6 billion, plant science innovations helped Canada's farmers supplied more than $5.2 billion in raw ingredients to Canada's animal farmers, millers, food and beverage processors, restaurants and biofuel industries.

Without plant science innovations, industries like biofuels and grain milling would most likely shrink. Canada has set regulatory requirements for ethanol use in gasoline, for example. If Canada's farmers had less access to plant science innovations, Canadian distillers would need to import more feedstock to meet demand or would import more ethanol from the U.S.

Animal production

Domestically produced grain is vital for Canada's animal production sector. According to the Animal Nutrition Association of Canada, fully 80% of all barley, 60% of corn and 30% of all wheat are produced for animal consumption. Feed accounts for up to 75% of all livestock costs, depending on the species(ANAC, n.d.). Without plant science innovations and local feed sources, Canada's livestock farmers may not be competitive on the international market. Overall, plant science innovations help supply $2.2 billion in feed directly to farmers and through Canada's animal food manufacturing industry.

Grain and oilseed milling

Canda's grain and oilseed milling industry is about as impacted by plant science innovations as Canada's animal production sector. Plant science innovations added $1.7 billion in local inputs.

Products of Canada's grain milling industry are mostly destined for export. Without the raw ingredients, the industry would certainly dwindle. Canada's animal production and other food manufacturers would likely shift to international sources of primary ingredients to meet Canadian consumer demand for products.

Ethanol production

Ethanol production is a crucial consumer in the agriculture value chain and continues to become a more valuable downstream industry. According to Jim Grey, Chair of Renewable Industries Canada, Canada's ethanol production reached $1.1 billion in revenue. It relied on $800 million in feedstock (Grey, 2018). As of 2015, Statistics Canada estimated that Canada's farmers supplied over $621 million in feedstock to the basic chemical manufacturing industry, making it the fifth-largest commercial purchaser of Canadian crops.

According to the USDA, Canada produces biofuel, primarily using corn and wheat. However, canola oil and soybean – both of which benefit tremendously from plant science innovations – are increasingly used as feedstock to produce biodiesel in Canada. In 2019, Canada's ethanol producers used 3.6 million tonnes of corn and 890 million tonnes of wheat. Biodiesel producers used 400 thousand tonnes of canola oil.

Ethanol and biofuel producers are poised for growth over the next few years if Canada passes new legislation mandating higher ethanol requirements in fuel. In its 2019 annual report on the biofuels market, the USDA estimated that Canada's 13 ethanol refineries are at only 85% capacity. In Canada, ethanol production has seen modest growth since 2011, about 20 million litres per year (United States Department of Agriculture (USDA) Foreign Agricultural Service, 2019). However, the biofuels industry is set to expand. Canada's draft regulation on Clean Fuel Standards could lead to much higher biomass requirements in Canadian fuels and propel the demand for new feedstock sources.

Food and beverage manufacturing

Canada's wineries, distillers, restaurants and other food manufacturers also used many crops made possible by plant science innovations. In total, Canada's food processors would need to source $1.1 billion more in crops if Canada's farmers did not have access to plant science innovations.

International Trade

Much of Canada's field crops, fruits and vegetables are exported to the United States. The export of Canada's crops allows citizens to import goods and services on better trade terms. Without crop protection products, Canada would lose out significantly on the gains from international trade.

Canada's global status as a major exporter of canola, oats, pulses and even blueberries relies on crop protection products and modern plant breeding. Over the past five years, Canada exported $24.3 to $26.3 billion per year of crops and related products. Oilseeds and cereals are the most important categories, with more than $16 billion exported every year.

Canada is by far a net exporter of agricultural products. Since 2015, Canada's crop production trade balance has fallen between $10 billion and $14 billion. Without plant science innovations, Canada would have likely exported $8.5 billion less or around 72% of Canada's net agricultural product trade balance in 2018/2019.

Table 11: Exports and Imports of Crops and Cereals, 2015 to 2019 ($ 000s)

	2015	2016	2017	2018	2019	2018-2019 Average	Plant science innovation impact
	Exports						

Cereals	9,366,128	7,448,694	8,145,510	9,317,061	8,914,053	9,115,557	2,892,488
Products of the Milling Industry; Malt, Starches, Inulin and Wheat Gluten	1,158,190	1,195,972	1,217,510	1,184,342	1,206,517	1,195,430	379,326
Oil Seeds, Oleaginous Fruits, Industrial or Medicinal Plants, Straw and Fodder	8,678,147	9,513,088	10,199,438	9,829,765	7,416,380	8,623,073	2,736,216
Edible Vegetables and Certain Roots and Tubers	6,232,074	6,399,605	5,827,227	5,295,542	5,805,616	5,550,579	2,101,802
Edible Fruits and Nuts	841,456	797,362	759,639	887,260	913,876	900,568	359,900
Sub-total	26,275,995	25,354,721	26,149,325	26,513,970	24,256,442	25,385,206	8,469,731
	Imports						
Cereals	1,054,346	930,061	899,696	1,208,550	1,367,762	1,288,156	
Products of the Milling Industry; Malt, Starches, Inulin and Wheat Gluten	372,851	398,441	398,039	366,258	395,867	381,063	
Oil Seeds, Oleaginous Fruits, Industrial or Medicinal Plants, Straw and Fodder	1,025,879	1,117,297	1,204,077	1,450,255	1,348,127	1,399,191	
Edible Vegetables and Certain Roots and Tubers	3,723,639	4,043,917	4,110,833	4,061,121	4,483,539	4,272,330	
Edible Fruits and Nuts	5,750,807	5,964,167	6,056,912	6,201,550	6,368,833	6,285,192	
Sub-total	11,927,522	12,453,883	12,669,557	13,287,734	13,964,128	13,625,931	
Net trade balance	14,348,473	12,900,838	13,479,768	13,226,236	10,292,314	11,759,275	

Source: ISED Trade Data Online

Consumer benefits

Thanks to plant science innovations, Canadian consumers can spend much less on groceries and access higher quality and longer-lasting produce.

Organic farmers are limited to non-synthetic pest control methods, which are usually less effective and labour-intensive. As a result, organic produce and food products require a significant production and retail price premium. However, the difference between conventional and organic produce and food products varies by product. Generally, the price premium for organic products ranged between 14% and as high as 174% in Canada in 2012(Hamzaoui-Essoussi & Zahaf, 2012). Most recently, in the U.S., only eight out of 131 organic products had the conventionally produced alternative. Organic price premiums were, on average, around 51%.

Table 12: Organic price premiums in the U.S. and Canada, selected studies

Study	Year	Area	Range
USDA	2021	United States	Weekly Organic price premium. Out of 131 products for the first week in January, only seven organic products were cheaper than non-organic. The unweighted average premium was 51%, with a 95% confidence interval of 16%.
Consumer Reports	2015	United States	On average, organic produce was 47% more expensive, although it was as high as 303% for soy products.
S. Islam	2013	Canada	Organic foods were 69% more expensive than their conventional counterparts. However, it varied from 13% to 155%, depending on the store and product category.
Essoussi and Zahaf	2012	Canada	Premiums in Canada range from 14% for apples to 174% for pork chops.
USDA	2010	United States	The USDA found that spinach had the lowest price premium in 2010, only 7%, but eggs[8] were 60% more expensive
Brown and Sperow	2005	United States	U.S. consumers could spend up to 70% more for an organic basket of goods in 2000.

Over time, the price premium has fallen somewhat, at least in the U.S. According to Nielsen, the price premium for organic food has declined over recent years, as farmers and retailers take advantage of economies of scale as consumer demand for organic food grows.

So, how much would Canadians need to spend if only organic products were available? As of 2019, Canadian households spent an average of $10,311 - on groceries ($7,536) and restaurants ($2,775). If Canadians only bought organic, the average household would spend between $2,500 and $6,400 more per year on food, based on prevailing organic price premiums of 25% to 65%.

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[8] Organic eggs require that chickens are fed a diet of organic grains.

Canada had 14.6 million households in 2019, so the total impact on Canadians' wallets would amount to $36.2 billion to $94 billion more per year in food costs, assuming Canadians already spend 4% of their budgets on organic agricultural products. On an overall average basis, if we assume an average 45% price premium for organic products (based on the observed range of 25% to 65% cited above), Canadians would have paid an extra $4,500 per household or $65.1 billion in total on groceries and in restaurants in 2019 if only organic products were available.

Of course, this analysis still underestimates the impacts of plant science innovations on Canadian wallets. Even organic farm systems still use many crop protection products that help prevent losses. Organic farmers may not use GM crop varieties. However, new varieties made through traditional plant breeding are still valuable for organic farmers.

Food Security

With more land needed for towns and cities, farmland will need to continue to become more and more productive to meet the dietary needs of million of more Canadians. According to Statistics Canada, Canada had the fastest population growth of all G7 countries in 2019 at 1.4.% per year. Canada's population will reach between 43 and 56 million by 2050.

Plant science innovations have driven yields across the world. In Europe, plant breeding alone contributed an increase in yields by 1.24% per annum(Noleppa, 2016), which would be enough to meet Canada's long-term food needs. Plant science innovations also make an enormous contribution to on-farm productivity. Plant science innovations ensure that Canada has access to a steady supply of food. In addition, future innovations in the sector will help Canada meet its continuing food requirements.

Value of farmland

Higher yields and more productive acreages, as well as a trend towards cash crops for export like canola, have helped drive a surge in the value of farmland in Canada.

Farmland value in Canada has widely outpaced housing and Canada's CPI in part because of plant science innovations. The cost of housing in Canada has risen by about 50% since 2002. In comparison, the price of farmland has more than tripled in part because farmers can now expect a higher return on investment to some degree because of better crop yield through better plant science innovations[9].

Farmland value is primarily driven by the possible economic rents from the land and the discount rate – or the cost of borrowing (see the discussion in (Eisenhauer & Toronto, 2011)).

Soybeans, canola, wheat and corn have all significantly benefited from both biotechnology and crop protection products. These four commodities also make up over three-quarters of Canada's

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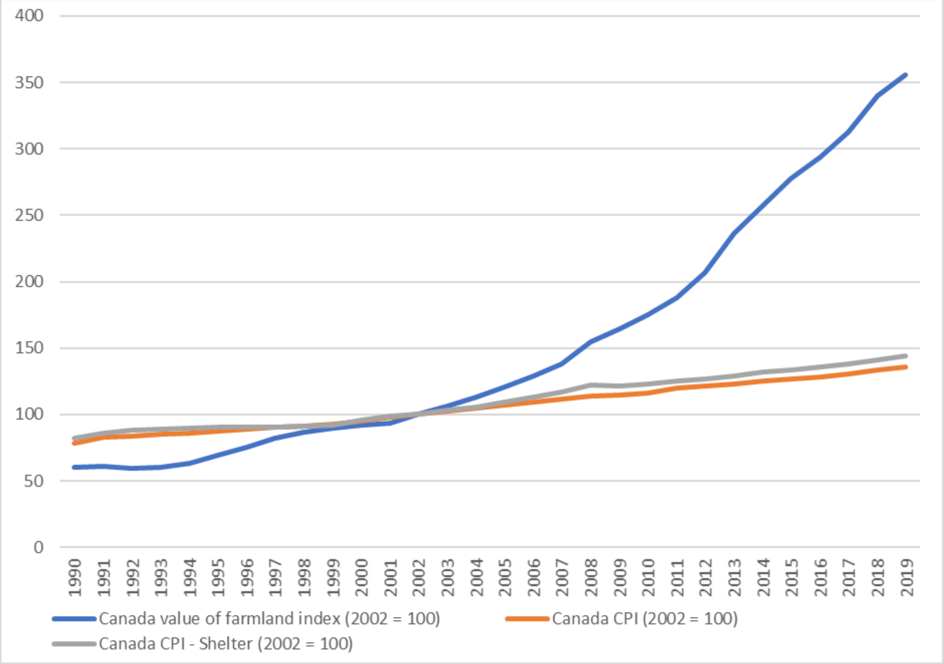
[9] Falling interest rates, revenue strength and economies of scale have contributed to the current trend, according to Farm Credit Canada.

total crop acreage, so there is no doubt that they have contributed to rising farmland values in Canada. Advancements in farm machinery productivity and management methods have also played a role in increasing the return to investment for farms in Canada.

Without plant science innovations, farmland prices would also fall in direct correlation to the lost future revenues. The strong relationship between revenues and farmland value could mean that farmland values would be as much as 31.7% lower, based on Eisenhauer and Mitchell's simple formula. However, farmers would partially offset lost revenues by choosing to plant species that grow the most effectively in their soil, even in the absence of plant science innovations. In the following section, we have estimated that farmgate revenues would fall 9.3% without plant science innovations, after accounting for dynamic productivity effects.

Given this range, Canada's farmland values could fall between 9.3% and 31.7% without plant science innovations.

Figure 3: Value of farmland compared to CPI in Canada, 1990 to 2019 (2002 = 100)



Source: Statistics Canada, Table 32-10-0047-01 and Table 18-10-0005-01. Author's calculations

Plant science innovations as a driver of productivity in Canada

In the previous section, we considered how integrated the crop protection industry is in the economy, otherwise known as its economic footprint. However, the analysis was static or *ceteris paribus* because it did not consider how farmers would adapt to different technological constraints and change their use of labour and other agricultural inputs.

If farmers were to no longer have any access to crop protection products or modern plant breeding techniques, they would change crop types and practices to reduce the negative impacts from a loss in productivity. One way they would do this is to adopt more labour-intensive practices. Gianessi, for example, estimates that U.S. farmers would need 17 billion more labour hours to control weeds manually rather than with herbicides (Gianessi & Reigner, 2007).

In effect, when the government approves or withdraws a crop protection product or GM variety from the market or limits access to plant science innovations, they affect the technology and production processes that farmers may use to produce. As a result, both on-farm and off-farm supply chains would reorganize to accommodate the loss in access to technology.

The economic impact would be observable in lower total factor productivity (TFP) – the efficiency that the crop industry can use capital, labour and intermediate inputs to produce field crops, fruits and vegetables.

In an alternative economy without using plant science innovations, farming labour and land use would increase to make up for the lost total factor productivity. Other inputs, such as fertilizer and fuel use, may expand as farmers adopt different farming methods, such as tillage based agriculture practices.

With lower farm production, farmers would change their inputs and supply less to downstream industries in the supply chain, like animal farmers, grain millers and even restaurants. Overall, fewer jobs would be needed in these industries. However, sectors like petroleum refineries may grow slightly because of increased demand for fuel.

Envelope Economics has developed the Canadian Labour-restricted Input-Output Model (CLIO Model^{TM}) to investigate how productivity and technology shocks in one industry affect the broader economy. Based on Statistics Canada's supply-and-use tables and labour data, the CLIO Model^{TM} allows one to measure how a technological shock will affect GDP, wages, and labour distribution across all of Canada’s 230 industries. The model includes over 100,000 data points that describe Canada’s interindustry, trade and consumption network-linkages.

To estimate the dynamic economic impacts of a loss of plant science innovation on productivity and the whole economy in Canada, we have included the following model assumptions:

- Fixed employment across supply chains[10]
- A fixed amount of total labour supplied by Canadian workers
- Perfectly complementary inputs
- A 27% reduction in agricultural chemical use (assuming that fertilizer use remains unchanged)
- A 22% increase in fuel use as a result of higher tilling (56% use no-till now with a ~40% reduction in fuel costs)

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[10] When consumers spend a fixed ratio of their income on a product category (i.e. they exhibit constant elasticity of substitution between different goods and services categories), the total amount of labour supplied is fixed across supply chains.

- A 23% decrease in Canada's total factor productivity in Canada's crop production industry, assuming that TFP returns to 1996 levels – the year before the commercialization of many GM plant varieties in Canada.

Results

Table 13: The impacts of a change in crop production technology

Industry	Estimated Value-added GDP impact (000s of dollars at market prices)	Change in industry revenues ($000s at market prices)	Change in employment (FTEs)
Crop production (except greenhouse, nursery and floriculture production)	-$385,910	-$3,333,464	21,926
Pesticide, fertilizer and other agricultural chemical manufacturing	-$378,424	-$1,025,214	-1,206
Animal production (except aquaculture)	-$125,636	-$497,536	-2,562
Grain and oilseed milling	-$115,063	-$670,897	-417
Truck transportation	-$79,258	-$198,487	-995
Electric power generation, transmission and distribution	-$77,020	-$107,936	-203
Meat product manufacturing	-$75,399	-$375,889	-768
Banking and other depository credit intermediation	-$74,039	-$96,793	-410
Miscellaneous wholesaler-distributors	-$71,070	-$124,400	-617
Repair construction	-$69,285	-$119,351	-732
Basic chemical manufacturing	-$59,083	-$189,383	-137
Food services and drinking places	-$58,727	-$129,273	-1,499
Other	-$1,447,532.92	-$3,034,599.70	-12,379
Total	**-$3,016,446.36**	**-$9,903,222.50**	**0**

Source: Statistics Canada Supply and Use Data, CLIO Model Results.

If Canada's farmers could no longer use crop protection products, overall Canadian GDP would drop by $3 billion, and economy-wide revenues would fall $9.9 billion. Most of the loss would be concentrated in the crop production sector and downstream industries. The crop production industry itself would lose an estimated $3.3 billion in revenues, and industry GDP would shrink by $386 million. The animal production and grain and oilseed milling industry would be the hardest hit sectors downstream. They would lose an estimated loss of $125 million in GDP and $115 million, respectively.

Farmers would use fewer pesticide inputs, so the agricultural chemical industry would shrink by $378 million in GDP and over $1 billion in revenues. However, petroleum refineries would see a modest $35 million uptick in revenues and $9 million in GDP.

Canada's labour market would also see a shift as nearly 22,000 FTE jobs or 44 million labour hours would be moved from connected sectors to the crop production sector to make up for the lost input productivity. In total, Canada's crop production sector's wages and profits would fall $21,600 per full-time employee. Canada's labour productivity across the whole economy would fall by an estimated $195 per worker per year.

Environmental Benefits of Plant Science Innovations in Canada

Generally, plant science innovations have significantly reduced the environmental impact of farming in Canada across several key areas:

- Improved pesticide use by generally reducing the environmental impact of pesticides
- Reduced the amount of land needed to feed Canada and the world
- Lowered GHG emission from lower fuel use and higher carbon sequestration
- Improved agricultural soil quality through less erosion, runoff and nutrients
- Supported on-farm biodiversity and by protecting Canada from invasive species

In particular, glyphosate is known to be "have a lower environmental impact quotient than most synthetic herbicide alternatives"(Duke, 2020). New herbicides and herbicide-tolerant crops have allowed Canada's farmers, especially those in Canada's western provinces, to adopt no-till and conservation till agricultural practices that have had significant benefits for soil biodiversity and near fields compared to traditional tilling methods. No-till agriculture has also substantially reduced the amount of fuel used to produce crops and, therefore, GHG emissions from farming operations.

The use of crop protection products, in particular, has allowed for more efficient agriculture, thus reducing the amount of land needed to produce enough food to feed the world. In Canada, plant science innovations have compensated for losing prime farmland to commercial and residential uses.

Across many measures, plant science innovations have helped protect biodiversity by reducing farmland expansion and allowing more land to be left for wildlife. Crop protection products can also be used to control invasive species to protect local animals and plants from invasive plants and animals.

Improved pesticide use

Brookes and Barfoot write that pesticides' environmental impact has fallen globally due to GMOs. It often allows for farmers to use less pesticide or apply glyphosate – a much less harmful pesticide than many previously used. Glyphosate can be used on a wide variety of plants. Previously, farmers would need to use a broader range of pesticides to manage different weeds.

Plant science innovations have allowed many farmers in Canada to use less pesticides to produce crops, measured in active ingredient and environmental impact quotient on their farms. For example, in Ontario, the amount of active ingredient per hectare has declined markedly for corn, soybeans and other grains, even though yields per acre have steadily improved (Farm & Food Care Ontario, 2015). Overall, corn and soybean production in Ontario has only a third of the pesticide intensity as 1983.

Table 14: Changes in pesticide use in Ontario, 1983 to 2013

		1983	1988	1993	1998	2003	2008	2013
Corn	Total kg ai	3,653,310	2,491,370	2,351,146	1,982,949	1,525,659	1,564,362	2,125,918
	kg ai per hectare	0.74	0.58	0.54	0.44	0.36	0.36	0.39
	ai per tonne	0.78	0.67	0.49	0.33	0.27	0.23	0.24
	Pesticide intensity (Index 1983 = 100)	100.00	85.77	62.63	42.38	35.24	29.32	30.33
Soybeans	Total kg ai	1,281,880	1,694,770	1,133,103	1,274,624	1,196,055	1,445,945	1,883,711
	kg ai per hectare	19.18	16.56	6.83	5.98	7.61	6.42	6.39
	ai per tonne	1.59	1.36	0.63	0.56	0.63	0.65	0.57
	Pesticide intensity (Index 1983 = 100)	100.00	85.58	39.64	35.10	39.41	40.90	35.91

Source: (Farm & Food Care Ontario, 2015)

On the other hand, farmers in Alberta have planted more hectares of canola and used more herbicides. In Alberta, the amount of active ingredient per tonne of output has increased from 0.47 kg of ai per tonne in 1988 to 0.68 kg per ai per tonne[11](*Overview of 2018 Pesticide Sales in Alberta*, 2020).

Of course, active ingredient does not necessarily capture the change in environmental risk, which has also been reduced significantly by some assessments. Traxler notes that farmers in Argentina significantly lowered or eliminated their use of Class II, III and U pesticides to control weeds on soybean farms (Traxler, 2006). In Western Canada, farmers reduced the environmental impact per hectare by 37% between 1997 and 2006 (Smyth, Gusta, Phillips, & Castle, 2010). Biden et al. estimated that a delay in adopting GM canola in Australia led to an additional 6.5 million kg in active ingredient use (Biden, Smyth, & Hudson, 2018).

In combination, plant science innovations like HT soybeans coupled with no-till farming may not change overall herbicide use. Keith Fuglie found no evidence that herbicide or fertilizer application rates are higher on fields with conservation tillage systems(Fuglie, 1999). The USDA similarly found that HT soybeans' adoption led to reduced tilling, without any impact on overall herbicide use(Jorge Fernandez-Cornejo, Charlie Hallahan, Richard Nehring, & Seth Wechsler, n.d.).

In 1992, scientists at Cornell introduced the Environmental Impact Quotient (EIQ): a formula created to provide growers with data regarding their pesticide options' environmental and health impacts to make better-informed decisions regarding their pesticide selection (Kovach, 1992).

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[11] Agricultural productivity was rather low in 2018

Table 15: Trends in the change in pesticide use in Canada from GM HT soybeans, 1997 to 2019

Year	KG AI savings	EIQ savings	% decrease in AI	% EIQ savings
1997	530	20,408	0.03	0.06
1998	25,973	1,000,094	1.8	3
1999	106,424	4,097,926	7.4	11.9
2000	112,434	4,329,353	7.34	11.9
2001	169,955	6,544,233	11.1	17.9
2002	230,611	8,879,527	15.7	25.4
2003	276,740	10,656,037	18.5	29.8
2004	351,170	13,522,035	20.4	32.8
2005	373,968	14,399,885	22.2	35.8
2006	84,130	10,191,227	4.8	24.5
2007	75,860	9,167,500	4.5	22.7
2008	96,800	11,726,000	5.6	28.5
2009	103,374	12,521,832	5.2	26.5
2010	113,729	13,776,201	5.4	27.3
2011	97,749	11,840,550	4.4	22.2
2012	119,977	14,533,032	5	25.3
2013	133,634	16,187,269	5	25.3
2014	149,969	18,165,957	3.7	24.1
2015	204,778	24,805,156	5.2	33.7
2016	517,955	19,967,913	13.1	26.9
2017	649,809	25,051,100	12.4	25.3
2018	569,214	21,944,043	12.5	25.6

Source: (Brookes & Barfoot, 2020)

Brookes and Barfoot estimate that Canada has used 569,214 kg less active ingredient in 2018 thanks to GM HT soybean's introduction alone. In total, they expect that Canadian farmers used 4.56 million kilograms less of active ingredient because of GM HT soybeans. The impacts are even more significant for GM corn and canola. They expect that the EIQ of corn is 17.8% lower due to GM innovations, a savings of 6.4 million kg of active ingredients from 1996 to 2018 (Brookes & Barfoot, 2020).

Similarly, they find that for canola – Canada’s top field crop – Canada’s farmers used 34.3 million kilograms less active ingredient with an EIQ reduction of 35.1%.

Table 16: Aggregate changes in pesticides use in Canada from GM crops, 1996 to 2018

	Change in active ingredient use, millions of kg ai (1996 to 2018)	% change in amount of active ingredient used	% of change in EIQ indicator
GM HT soybeans	-4.56	-8.8	-24.1
GM HT Corn	-6.4	-9.7	-17.8
GM HT canola	-34.3	-25.2	-35.1

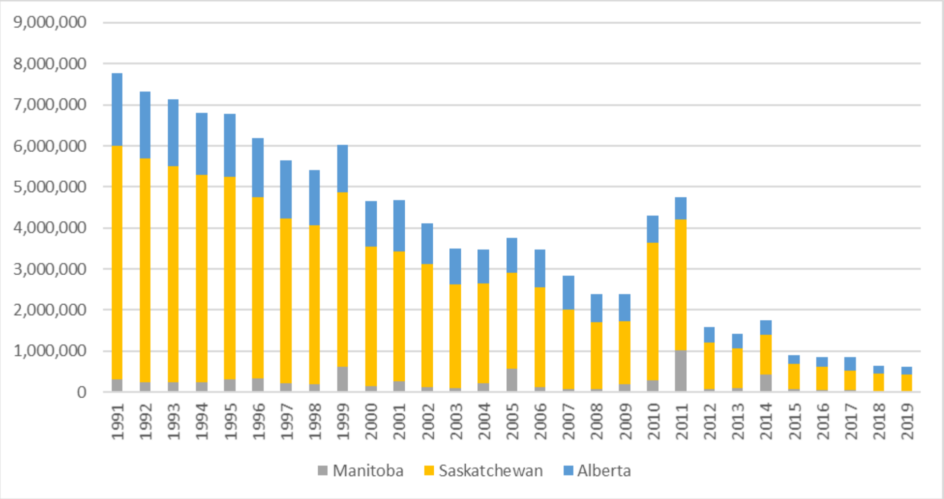
Source: (Brookes & Barfoot, 2020)

More efficient land area use

Canada's total farmland area has declined slightly over the past few decades. Although farms now leave much less area overall, farmers leave less land fallow and use more for seeding crops. According to Statistics Canada, the massive drop in summer fallow is attributed to technological and economic changes[12].

Plant science innovations have played a significant role in reducing summer fallow because they allow farmers to use no-till methods. Traditionally, farmers in Canada's western provinces would leave a percentage of acres to fallow every summer and use tilling to control weeds. They fallowed land to help soil store moisture to be available during the following growing season. However, summer fallow is known to be deleterious to the environment. In Gan et al., the authors state that "*a growing body of evidence has shown that summer fallow has serious environmental consequences. Tillage during the summer fallow period disturbs the soil, encourages soil erosion and generates dust that affects soil, air and water quality*."(Gan et al., 2015)

Figure 4: Timeline of Summer fallow hectares by Western province, 1991 to 2019



Source: Statistics Canada. Table 32-10-0002-01 Estimated areas, yield and production of principal field crops by Small Area Data Regions, in metric and imperial units. Large amounts of flooding left fields too wet to seed in 2010 and 2011, leading to more land left fallow. Rainy weather and flooding in 1999, 2005, and 2011 in Manitoba caused similar increases in summer fallow.

Farmers, particularly those in the West, can now use more of their land for annual crop production. Plant science innovations have made each hectare more productive by losing far less crop to pest damage. Since 1997, the average field crop in Canada yields 43% more product per hectare. Yields for soybeans, oats, sunflower seeds and wheat are all up over 50%.

Figure 5: Field crop yields for canola, oats, sunflower seeds, and wheat (Index 1997=100)

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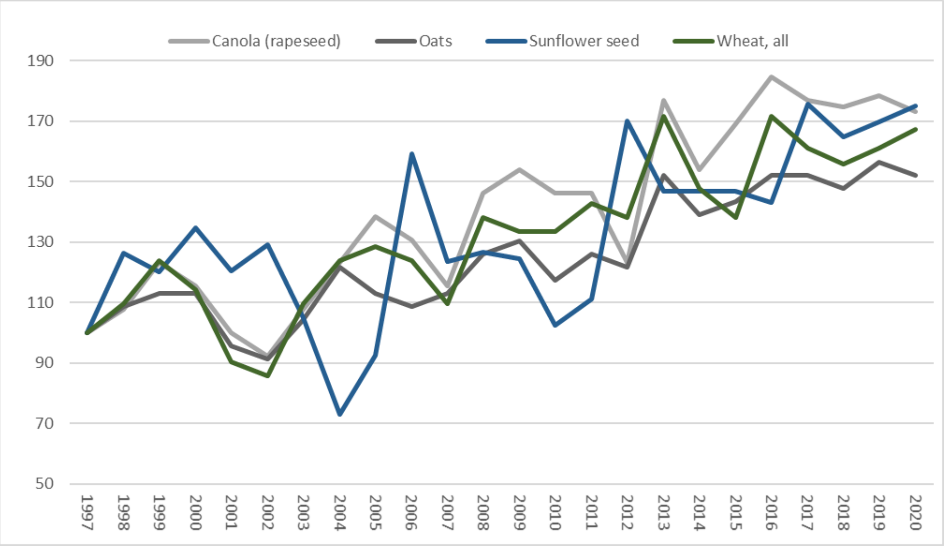
[12] Statistics Canada. Table 32-10-0406-01 Land Use.



If Canada's farmers were to produce the same amount of crops in 2019 without plant science innovations, they would need 13.6 million more hectares of suitable land – or 44% more land. This area is slightly larger than the surface area of all maritime provinces combined (13 million hectares). Canada would be under much more pressure to convert wildlife habitat to farmland without using plant science innovations.

Table 17: Additional area required to grow the same amount of crops without plant science innovations by province and commodity group, 2019 (ha)

	Crops	Fruit	Vegetables	Potatoes	Total
Newfoundland and Labrador	0	91	167	181	440
Prince Edward Island	23,025	1,727	487	47,613	72,853
Nova Scotia	10,982	7,102	1,493	891	20,468
New Brunswick	10,858	5,357	387	29,459	46,060
Quebec	503,694	17,530	28,209	24,229	573,662
Ontario	1,306,253	19,831	35,225	18,949	1,380,258
Manitoba	1,910,229	82	972	38,982	1,950,264
Saskatchewan	6,118,153	126	205	3,508	6,121,992
Alberta	3,286,789	108	2,583	34,101	3,323,580
British Columbia	51,883	16,324	3,915	3,731	75,853
Total	13,233,971	68,582	74,177	201,644	13,578,374

Source: Author's calculations

The majority of the benefit derives from field crops. Canada's farmers continue to grow more cash crops, specifically canola (a result of Canadian modern plant breeding itself), that benefit significantly from plant science innovations. Without plant science innovations, Canada would need to find nearly double the amount of suitable land or 8 million more hectares to grow the same amount of canola.

GHG reduction from reduced farmland area

If Canada had to expand its cropland to meet the demand for agricultural products, the new land would likely come from forests and pastures adjacent to existing farmland. Forests and grassland act as a carbon sink, so expanding farmland would harm Canada's GHG emissions.

According to Environment and Climate Change Canada (ECCC), changing one hectare of forest to cropland in Eastern Canada has a long-term GHG emission impact of 17 to 22 tonnes of carbon per hectare or 62 to 80 tonnes of CO2 equivalent (pg. 166 (ECCC, 2020)). According to the ECCC methodology, a change of forest to cropland in Canada's Western provinces is carbon neutral or very slightly positive because most areas that adjoin grassland areas store comparatively less carbon.

If Canadian farmers were to maintain the current crop mix but not use plant science innovations, they would need an extra 2.1 million hectares in Canada's Eastern provinces. It is quite conceivable then that in the best-case scenario, a return to previous cropland levels would add between 130 and 169 million tonnes of CO2 equivalent GHG emissions into the atmosphere if more cropland were required in Canada's Eastern provinces or 130 to 169 billion kgs.

Environmental benefits from no-till and conservation tillage

Canada's farmers have quickly moved towards no-till farming practices that limit disturbing the soil, resulting in extensive ecological benefits. Since the introduction of HT GM crops to Canada in 1995, farmers have tilled 30 million fewer acres. Overall, Canadian farmers used no-till agriculture on 19 million of 33 million acres in Canada in 2016 or corresponding to 58% of all cropland in Canada in 2016.

Tillage involves stirring the soil to reincorporate plant debris to destroy pests and improve nutrients. However, this process increases erosion and water loss. Conservation tillage is a generic term for tillage systems that can conserve water and soil by reducing their loss to tilling. No-till agriculture is the complete elimination of tilling in a particular area(Carter, 2004).

Conservation tillage and no-till agriculture require the use of plant science innovations to be economical. Farmers often apply herbicides like glyphosate to replace tilling to eliminate fast-growing weeds. Herbicide-tolerant GM crops have made weed control more effective and less costly.

Plant science innovations, especially HT crops, explain the high adoption of no-till agriculture. The USDA found that only a little over 10% of farmers growing HT soybeans used conventional tilling practices, compared to 60% of farmers not using HT soybeans(Jorge Fernandez-Cornejo & Mike Livingston, 2014).

Table 18: Total acres by tilling practice in Canada, 1991 to 2016 (acres)

Year	Conventional tillage	Conservation tillage	No-till seeding
1991	49,387,997	17,522,247	4,821,406
1996	37,891,867	21,663,137	11,346,533

2001	29,750,778	21,918,819	21,803,302
2006	20,114,443	18,354,767	33,311,822
2011	13,897,893	17,954,616	41,241,494
2016	14,117,179	19,339,204	48,172,870

Source: Statistics Canada, Census of Agriculture

No-till agriculture has many environmental benefits. When farmers no longer need to disturb the soil for weed protection, it can maintain its many ecological services, including lower GHG emissions, higher soil quality, and better biodiversity.

Lower GHG emissions from carbon sequestration and lower fuel use

According to Brookes and Barfoot, for soybeans alone, Canada has sequestered an additional 838.1 million kgs of carbon thanks to no-till and conservation tilling practices since 1997. The sequestered carbon amounts to an equivalent of removing over 3 billion kgs of carbon dioxide from the atmosphere.

HT canola had an even more significant impact on soil sequestration. Brookes and Barfoot reckon that HT canola helped sequester 3,372 million kgs of carbon in the soil, reducing carbon dioxide emissions a further 12,374 million kgs.

Less tilling has also led to significant fuel consumption savings. According to Brookes and Barfoot, Canadian farmers saved 220.2 million litres of fuel between 1997 and 2018, which reduced emissions by 588 million kgs because of no-till and conservation tilling practices for soybeans alone. They estimate that HT canola further reduced fuel use by an additional 918 million litres, reducing carbon dioxide emissions by an extra 2,451 million kgs. In total, Brookes and Barfoot calculate that Canada has avoided 3.3 billion kgs of CO2 emissions from reduced fuel use and 16.5 billion kgs from soil carbon sequestration.

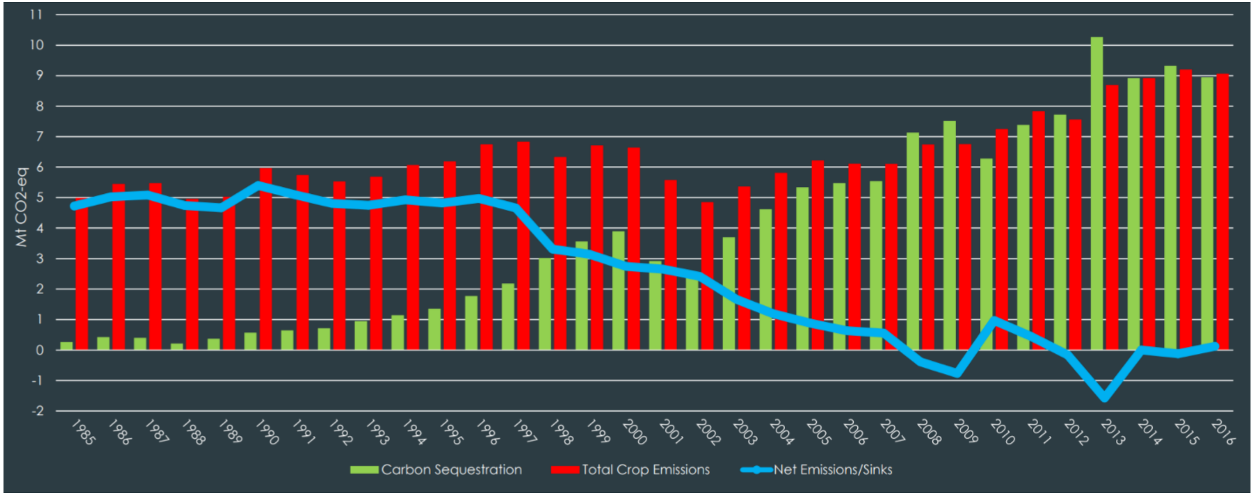
Table 19: Potential CO2 Savings in Canada from HT crops, 1996 to 2018

Crop and trait	Permanent fuel savings (million litres)	Potential CO2 savings from reduced fuel (million kg CO2e)	Potential carbon dioxide savings from soil carbon sequestration (million kg CO2e)
HT Soybeans	220	588	3,076
HT Canola	918	2,451	12,374
HT Corn	106	282	1,096
Total	1,244	3,321	16,546

Source: (Brookes & Barfoot, 2020)

In a 2019 study, Lana Awada projected that changes in tilling practices made Saskatchewan's crop production sector change from a net polluter emitter of GHGs to near climate neutral. Awada figured that the Saskatchewan crop sector went from net GHG emissions of 5 million tonnes of C02 equivalent in 1985 to just 0.1 by 2016, a 98% decrease. It is important to note that her analysis also took into account the higher GHG emissions from higher fertilizer use (Lana Awada, 2019).

Figure 6: Net GHG Emission/Sink in Saskatchewan's Agriculture Sector, 1985-2016



Source: Lana Adawa, Measuring Greenhouse Gas Emissions In The Saskatchewan Crop Sector, *Presentation at the APAS,* 2019

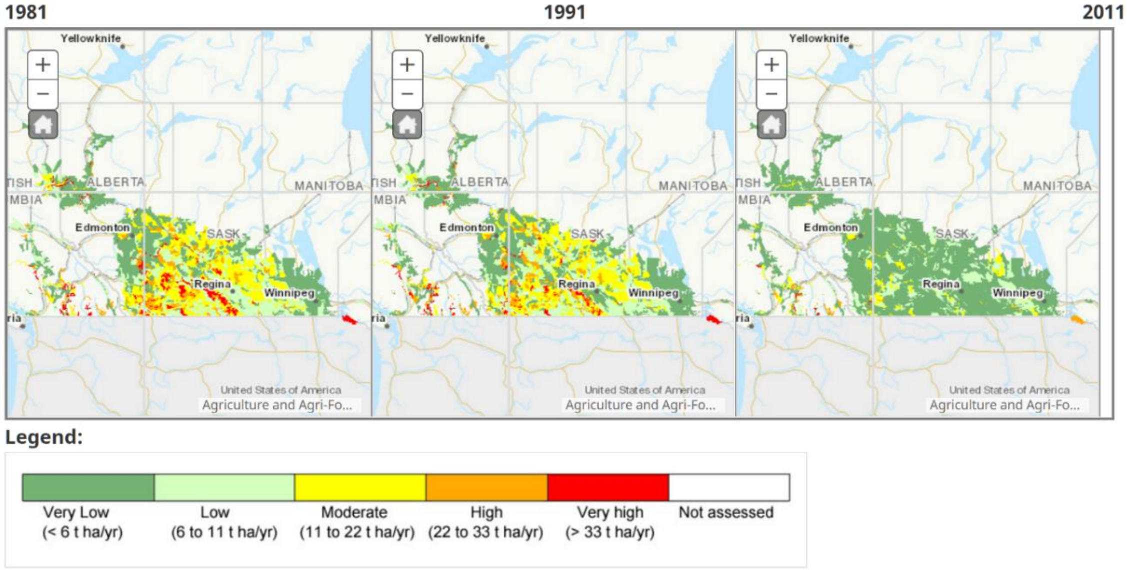
Reduced erosion

In 1980, soil erosion cost Canada's Western provinces more than $1 billion in losses. However, the adoption of no-till agriculture has greatly improved reduced soil erosion. For example, Lana Awada finds that the primary cause of land degradation on the Prairies was conventional tillage, in conjunction with the then predominant summer fallow cropping practices. She found that between 1991 and 2006, the percentage of cropland in the "Very Low soil erosion risk class" increased from 63% to 87% in Alberta, from 48% to 87% in Saskatchewan, and from 63% to 79% in Manitoba (L. Awada, Lindwall, & Sonntag, 2014). Soil erosion risk has continued to drop, according to AAFC.

According to a report for the Canadian Field Print Initiative, soil erosion has significantly declined in both Western provinces and Ontario due to conservation tillage practices (Canadian Field Print Initiative, 2016).

In Seitz et al., the authors found that conventional agriculture with no-till practices had the lowest amount of soil erosion compared to organic till/no-till and conventional till agricultural practices. Although no-till practices can significantly reduce erosion in organic and conventional farming, the impact of no-till practices in conventional farming is more significant (Seitz et al., 2019).

Figure 7: Soil erosion risk by class, 1981, 1991 and 2011



Source: AAFC Soil Erosion Indicator, 2020

Less soil, nutrient and pesticide runoff

No-till agriculture also reduces soil losses to water leaching and runoff.

A U.S. study similarly found that no-till systems reduced the soil runoff rate by 79% compared to chisel till farming practices. However, the authors found no effect on losses of agricultural chemicals applied to the land (Gonzalez, 2018). Wuest et al. also found that no-till agriculture nearly eliminated soil erosion and runoff events (Wuest, Williams, Gollany, Siemens, & Long, 2008).

Awada also reported that no-till soils had increased available plant nutrients, including phosphorus, potassium and mineralizable nitrogen. DeLaune also found higher phosphorus and ammonium-N runoff in no-till systems(DeLaune & Sij, 2012).

No-till crop methods also have the potential to protect sensitive habitats because they may further reduce pesticide runoff into nearby lakes and streams by 90% (L. Awada et al., 2014). However, the impact depends on the compound (Elias, Wang, & Jacinthe, 2018).

Higher biodiversity

Agriculture can reduce biodiversity by reducing natural habitats for plants and animals and increasing desertification (FAO, 2019). Minimizing the area required for agriculture supports the environment. At the same time, higher biodiversity supports agricultural production by providing ecosystem services such as pollination, pest control, soil formation and maintenance, carbon sequestration, purification and regulation of water supplies, reduction of disasters threats, and the provision of habitat for other beneficial species (ibid). It is in farmers' interest to preserve on-farm biodiversity using plant science innovations, particularly when they improve yields.

Plant science innovations have supported biodiversity on and off Canadian farms by:

- reducing the amount of land required for agriculture in Canada;
- improving the soil environment for microbes and arthropods because of no-till farming;
- supporting habitat for birds and mammals near fields;
- and helping Canada manage invasive species

As shown above, plant science innovations allow for more intensive and less extensive agriculture, protecting more areas of the world from habitat loss. In Canada, farmers would need 13.6 million more hectares of suitable land to produce the same amount of crops, fruits and vegetables. Indeed, Canada's total farmland area has declined from 68.7 million hectares in 1971 to 64.2 million hectares in 2016, even though cropland has increased. Canadian farmers have been able to use farmland more efficiently by avoiding summer fallow, which has negative impacts on on-farm biodiversity.

No-till methods improve soils for microbes and arthropods that make the soil their home. When the soil is not disturbed, microbes and arthropods are more easily able to sustain themselves. A 2012 study found that no-till systems increased soil organic matter and showed 71% greater microbial biomass and a higher abundance and diversity of arthropods (Sapkota et al., 2012).

No-till has been shown to increase wildlife habitat in Canada and the U.S. Baig et al. state that "crop residue provides food in the form of waste grain on the soil surface and feeds waterfowl, songbirds, upland game birds, deer, small mammals, and increased populations of arthropods in spring and summer. Small mammals and many bird species depend on insects as their primary food source." They also find that no-till fields have a higher density of bird nests than tilled fields (Baig & Gamache, 2011).

Finally, crop protection products are also a method to tackle invasive species competing for native flora and fauna resources. Many agricultural weeds that are now controlled with crop protection products were originally invasive species. David Pimental reports that 73% of weeds are alien species in the U.S. (Pimentel, 2014). The North American Invasive Species Management Association recognizes that pesticides are an essential tool to stop invasive species when preventative measures have failed (North American Invasive Species Management Association, 2020). Herbicide treatments are also recommended to control extensive populations of invasive phragmites in Ontario(*Invasive Phragmites (Phragmites australis)*, n.d.). In British Columbia, the Invasive Species Council of BC reports that pesticides are applied to eliminate invasive gypsy moths and sea lampreys.

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Annex I: Summary of Pesticide Sales in Canada, Top 10 Agricultural Active Ingredients, 2017

Active Ingredient	Product Type	Sales volume (kgs of active ingredient)
Glyphosate	Herbicide	>50,000,000
Surfactant blend	Other	>1,000,000
Available chlorine, present as sodium hypochlorite	Antimicrobial	>1,000,000
Glufosinate ammonium	Herbicide	>1,000,000
2,4-D	Herbicide	>1,000,000
Mineral oil[13]	Insecticide/Fungicide/Other	>1,000,000
Mancozeb	Fungicide	>1,000,000
MCPA	Herbicide	>1,000,000
Bromoxynil	Herbicide	>1,000,000
S-metolachlor and R-enantiomer	Herbicide	>500,000

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[13] Mineral oil is suitable for organic crop production.

Annex II: Farming area impacts of a total or partial ban on plant science innovations

Area impacts by field crop

	Average Area (hectares)	Average Production (tonnes)	Weighted % Yield Loss without Plant Science Innovations	Additional Area Required if no plant science (hectares)
Barley	2,727,500	10,382,600	18.4%	613,394
Beans	150,200	316,800	13.6%	23,723
Canary seed	99,100	147,500	9.5%	10,451
Canola (CP)	8,319,200	18,648,800	35.1%	5,421,486
Canola (MPB)			17.7%	1,704,729
Chick peas	155,800	251,500	8.3%	14,176
Corn (CP)	1,801,000	25,801,400	25.0%	726,700
Corn (MPB)			18.5%	380,016
Flaxseed	341,800	339,300	14.6%	58,501
Lentils (CP)	1,488,600	2,166,900	8.3%	147,749
Lentils (MPB)			10.0%	135,226
Mustard seed	154,700	134,600	7.2%	12,082
Oats	1,171,100	4,237,300	15.0%	206,697
Peas dry	1,711,000	4,236,500	15.8%	320,642
Rye all	102,600	333,400	6.9%	7,628
Soybeans (CP)	2,270,500	6,045,100	26.5%	881,641
Soybeans (MPB)			8.7%	180,675
Sugar beets (CP)	12,400	903,800	25.3%	4,675
Sugar beets (MPB)			10.0%	1,378
Sunflower (CP)	28,800	62,900	25.2%	9,894
Sunflower (MPB)			10.0%	640
Wheat (CP)	9,655,500	32,347,800	20.7%	1,494,576
Wheat (MPB)			10.0%	1,072,833
Field Crop Sub-total	**30,189,800**	**106,356,200**	**31.7%**	**13,429,513**

Notes: CP = crop protection, MPB = modern plant breeding

Area impacts by fruit

	Average Area (hectares)	Average Production (tonnes)	Weighted % Yield Loss without Plant Science Innovations	Additional Area Required if no plant science (hectares)
Apples	16,846	377,929	45.7%	14,198
Apricots	130	982	50.8%	134

Blueberries	76,682	176,127	23.8%	23,913
Cherries sour	926	4,591	50.2%	935
Cherries sweet	2,125	22,079	50.2%	2,145
Cranberries	7,188	172,440	29.6%	3,025
Grapes	12,518	115,498	59.3%	18,210
Nectarines	308	3,435	44.3%	245
Peaches	2,465	22,862	39.0%	1,575
Pears	830	9,668	31.1%	375
Plums and prunes	608	3,642	55.5%	758
Raspberries	1,962	9,145	24.2%	625
Strawberries	3,677	27,252	39.9%	2,443
Total	**126,265**	**945,650**	**40.0%**	**68,582**

Area impacts by vegetable

	Average Area (hectares)	Average Production (tonnes)	Weighted % Yield Loss without Plant Science Innovations	Additional Area Required if no plant science (hectares)
Asparagus	2,159	10,235	37.6%	1,298
Beans	7,842	61,116	32.6%	3,801
Beets	1,754	52,222	33.4%	882
Broccoli	4,108	42,313	48.6%	3,880
Brussels sprouts	631	6,757	52.7%	704
Cabbage	5,285	163,881	46.9%	4,668
Carrots	7,943	360,195	41.7%	5,685
Cauliflower	1,756	31,598	45.9%	1,488
Celery	748	32,441	47.0%	662
Corn	16,227	189,554	41.4%	11,441
Cucumbers	2,432	59,612	60.5%	3,728
Dry onions	5,417	250,847	43.9%	4,246
Garlic	537	1,248	34.5%	283
Leeks	327	6,413	38.1%	201
Lettuce	3,776	84,902	51.4%	3,987
Other melons	441	12,472	48.3%	412
Parsley	129	1,898	18.3%	29
Parsnips	319	6,264	52.7%	356
Peas	10,535	47,775	51.6%	11,247
Peppers	2,223	63,438	52.7%	2,481
Pumpkins	3,067	75,855	44.4%	2,447
Radishes	1,016	15,618	48.3%	949
Rhubarb	155	1,656	27.9%	60
Rutabagas and turnips	1,422	44,613	40.6%	970
Shallots	707	16,269	43.9%	552

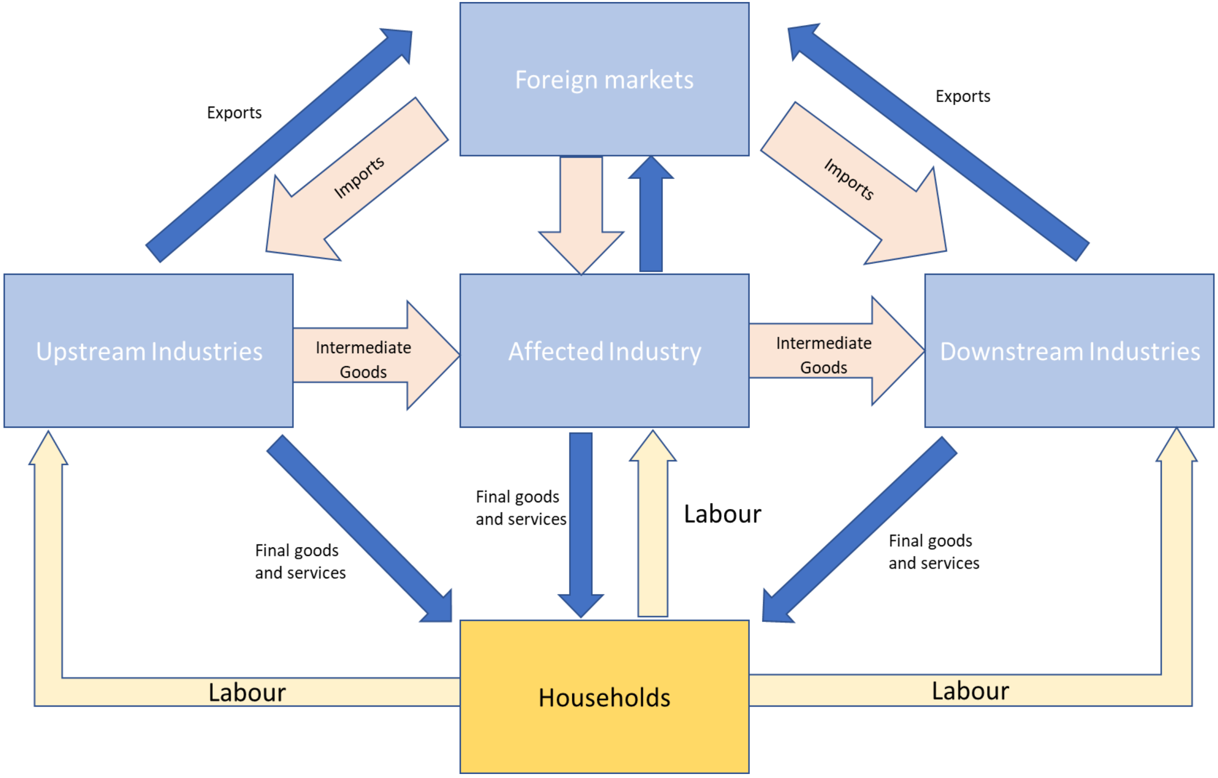
Spinach	569	4,607	49.4%	556
Squash and zucchinis	2,877	53,877	39.5%	1,876
Tomatoes	5,906	490,286	42.8%	4,421
Watermelon	706	32,942	50.7%	727
Total	**91,014**	**2,220,904**	**44.8%**	**74,038**
Potatoes	**362,095**	**106,486**	**35.8%**	**201,644**
Field Crop Sub-total	**30,189,800**	**106,356,200**	**31.7%**	**13,429,513**
Fruit Crop Sub-total	**126,265**	**945,650**	**40.0%**	**68,582**
Vegetable Sub-total	**91,014**	**2,220,904**	**44.8%**	**74,038**
Grand Total	**30,769,174**	**109,629,240**	**32.8%**	**13,773,777**

Annex III: Methodology of the economic impact of a total or partial ban on plant science innovations in Canada

The following models consider different economic conditions within an industry, given various combinations of fixed production prices and labour market slack. However, the same graph applies for all scenarios, even though the production function and assumptions on prices may not.

We will assume that consumers do not buy directly from foreign markets, but only indirectly as they are used in production, i.e. sales of goods and services from foreign markets pass through a wholesaler or retailer.

Figure 8: The exchange of goods, services and labour in a target industry



Note: This omits financial flows.

In the examples, the following equalities always hold, even though the production function and flexibility in prices changes:

Households utility function and budget constraint:

$$Cobb - Douglas\ utility\ function:\ Utility = \prod_{i=1}^{N} C_i^{\alpha_i}$$

$$Exponents\ of\ the\ utility\ function\ sum\ to\ 1: \sum_{i=1}^{N} \alpha_i = 1$$

$$Labour\ supply\ when\ fixed: \sum_{i=1}^{N} L_i = L$$

$$Budget\ constraint: \sum_{i}^{N} p_i\, C_i = \sum_{i}^{N} w_i\, L_i + \sum_{i}^{N} \pi_i$$

In a competitive economy all $\pi_i = 0$.

Producers:

$$Profitmaximization: \pi_i = p_i f(A, L_i, K_i, I) - w_i L_i - r_i K_i - p_I I$$

$$Output: C_i + X_i + dom.I_i = f(L_i, K_i, I)$$

Where I is a collection of domestic and international intermediate inputs, and p_I is the weighted average price.

$$Capital\ supply\ is\ fixed: \sum_{i=1}^{N} K_i = K$$

For the economy:

$$Total\ Output = \sum_{i}^{N} p_i C_i + \sum_{i}^{N} p_i X_i + \sum_{i}^{N} p_i\ dom.I_i$$

$$Gross\ Domestic\ Product = \sum_{i}^{N} p_i C_i + \sum_{i}^{N} p_i\, X_i - \sum_{i}^{N} p_m\ inter.I_i$$

Adding in exports and imports allows firms to trade for goods that they can use in production for consumption goods. With balanced trade, society will allocate labour towards exports, such that:

$$Balanced\ trade: \sum_{i}^{N} p_i\, X_i = \sum_{i}^{N} p_m\ inter.I_i$$

In national growth accounting, the marginal impacts of a shock are often split into three different types of impacts:

Direct impacts – The macroeconomics impacts from a change in output within the industry *a* – the affected industry.

$$\text{Direct output impact } = \Delta p_a \, f(A, K_a, L_a, I)$$

$$\text{Direct wage impact } = \Delta w_a \, L_a$$

$$\text{Direct GDP impact } = \Delta p_a \, f(L_a, I) \; - \; q \; * \; inter.I_a$$

Indirect impacts – The macroeconomic impacts from suppliers providing goods and services to the affected industry *a* (and their suppliers to them and so on).

$$\text{Indirect output impact } = \sum_{i \neq a} \Delta \, p_i \, f(A, K_i, L_i, I)$$

$$Indirect\ wage\ impact \ = \sum_{i \neq a} \Delta \, w_i \, L_i$$

$$\text{Indirect GDP impact} = \sum_{i \neq a} \Delta \, p_i \, f(A, K_i, L_i, I) - \mathrm{p_m} * \mathrm{inter.I}_i$$

The following models consider a change in regulation that reduces the amount of labour that the industry must spend on administrative tasks. Essentially, reducing the amount of labour required for a given level of production. Such administrative burden reduction reforms were very common through OECD countries around the time of the 2008-9 financial crisis.

To build intuition for how this works in practice, we will simplify the problem. Let us start by considering an economy with multiple simple supply chains with linear production functions and no exports, where consumers have standard Cobb-Douglas preferences. The total supply of labour form households is fixed, and we will leave out capital[14], so the social planning problem is just one of distributing labour between the several sectoral supply chains. We will define the production functions of N sectors as simple Leontief production functions[15].

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[14] The solution for capital would be identical to labour, if there is a Hicksian technology change as a result of a regulation.

[15] This model would actually generalize nicely with exports and a fully interconnected economy, although the math gets a little bit harder to interpret.

$$\mathrm{Y}_F = f(A_F, L_{iF}, I) = min\left(A_{iF}L_{iF}, I_{j1,}I_{j2}, \dots\right)$$

$$\pi_{iF} = p_{iF}min(A_{iF}L_{iF}, I) - w_i L_i - \sum_{i\,=\,1}^{N} p_{jiI} I_j I$$

$$\pi_{iI} = p_{iI}A_{iI}L_{iI} - w_{iI}L_{iI}$$

Labour in the supplier industries and the final good industry are thus directly linked. For each supplier industry:

$$L_{iF} = \frac{A_{iI}}{A_{iF}} L_{iI}$$

With competitive markets and fixed prices:

$$p_{iF}(A_{iF}L_{iF}) = \; w_{iF}L_{iF} + \textstyle\sum_{n\,=\,1}^{N} p_{iI} \frac{A_{iF}}{A_{iIn}} \; L_{iF} \quad \text{(zero profit condition)}$$

If prices are fixed, wages must rise in direct proportion in the affected part of the supply chain in response to a change in technology.

Solving for the change in GDP, we find a few stylised facts:

1. Labour is fixed across supply chains.
2. When the technology improves, labour will leave the affected industry into other parts of the supply chain.
3. The GDP of the whole economy changes approximately proportionate to the change in output per worker. i.e.
$$\sim\Delta\text{Total } GDP = \sim\Delta A * \frac{Industry\ sales\ revenue}{Total\ GDP}$$
4. With fixed prices, wages change in direct proportion to the change in TFP in the affected industry.

Annex IV: Crop yield loss estimates by paper and author

Part I

Crop	*McCrae*	*Popp*	*Badgley*	*StatsCan 1*	*StatsCan 2*	*Scottfarm*	*Knutson*	*Pimentel*	*De Ponti*	*Nazarko*	*Oerke*	*Adenle*	*Palmer*
Barley	10.0%		7.2%			23.1%			31.0%	25.4%	21.0%		
Beans dry white	10.0%		18.4%						12.0%				
Beans coloured	10.0%		18.4%						12.0%				
Canary seed	10.0%		18.4%						19.0%				
Canola	30.0%								18.0%				
Chickpeas	10.0%		18.4%						9.0%				
Corn for grain	15.0%	37.0%	7.2%				32.0%	30.7%	11.0%		33.0%	8.0%	
Corn for Grain (Crop Protection)	15.0%	37.0%	7.2%				32.0%	30.7%	11.0%		33.0%	8.0%	
Flaxseed	15.0%		7.2%						35.0%				
Lentils	10.0%		18.4%						9.0%				
Mustard seed	10.0%		7.2%										
Oats	5.0%		7.2%						15.0%	25.4%			
Peas dry	10.0%		18.4%						15.0%				
Rye all	5.0%		7.2%						24.0%				
Soybeans	15.0%	34.0%	18.4%				37.0%	0.0%	8.0%		34.0%	0.0%	
Sugar beets	10.0%										56.0%		
Sunflower seed	10.0%		1.0%						23.0%				
Wheat, all excluding durum wheat	10.0%	22.0%	7.2%			23.1%	24.0%		27.0%	25.4%	21.0%		

Asparagus	25.0%		12.4%	45.8%	55.0%				23.0%				
Beans	25.0%		12.4%	70.5%	12.0%				23.0%				
Beets	25.0%		12.4%	45.5%	56.0%				23.0%				
Broccoli	25.0%		12.4%	42.9%	44.0%				23.0%				
Brussels sprouts	25.0%		12.4%						23.0%				
Cabbage	25.0%		12.4%	45.4%	37.0%				23.0%				
Carrots	25.0%		12.4%	13.5%	40.0%				11.0%				
Cauliflower	25.0%		12.4%	47.6%	55.0%				23.0%				62.0%
Celery	25.0%		12.4%						23.0%				
Corn	25.0%	37.0%	12.4%	-24.9%	-52.0%		32.0%		11.0%			8.0%	
Cucumbers	25.0%		12.4%						23.0%				
Garlic	25.0%		12.4%	-11.5%	8.0%				23.0%				
Leeks	25.0%		12.4%						23.0%				
Lettuce	25.0%		12.4%	65.3%	52.0%		67.0%		14.0%				
Dry onions	25.0%		12.4%	57.2%	63.0%		64.0%		23.0%				
Other melons	25.0%		12.4%						23.0%				
Parsley	25.0%		12.4%						23.0%				
Parsnips	25.0%		12.4%						23.0%				
Peas	25.0%		12.4%						23.0%				
Pumpkins	25.0%		12.4%	51.5%	44.0%				23.0%				
Shallots	25.0%		12.4%						23.0%				
Spinach	25.0%		12.4%						23.0%				
Squash and zucchinis	25.0%		12.4%	31.7%	27.0%				23.0%				
Tomatoes	25.0%		12.4%	23.6%	23.0%		77.0%		19.0%				
Peppers	25.0%		12.4%						23.0%				
Radishes	25.0%		12.4%						23.0%				
Rhubarb	25.0%		12.4%						23.0%				
Rutabagas and turnips	25.0%		12.4%		6.0%				23.0%				

Watermelon	25.0%		12.4%				23.0%		
Apples	30.0%		4.5%	15.4%	21.0%	100.0%	31.0%		
Apricots	30.0%		4.5%				22.0%		
Blueberries	30.0%		4.5%	17.1%	-38.0%		22.0%		
Cherries sour	30.0%		4.5%				22.0%		
Cherries sweet	30.0%		4.5%				22.0%		
Cranberries	30.0%		4.5%		-30.0%		22.0%		
Grapes	30.0%		4.5%			89.0%	22.0%		
Nectarines	30.0%		4.5%		48.0%		22.0%		
Peaches	30.0%		4.5%	20.0%	30.0%	81.0%	22.0%		
Pears	30.0%		4.5%	-27.5%	-22.0%		22.0%		
Plums and prunes	30.0%		4.5%				22.0%		
Raspberries	30.0%		4.5%	-72.9%	9.0%		22.0%		
Saskatoon berries	30.0%		4.5%				22.0%		
Strawberries	30.0%		4.5%	25.0%	9.0%		41.0%		
Potatoes	25.0%	75.0%	10.9%			57.0%	30.0%	50.0%	20.9%

Part II

Crop	*Seufert*	*Entz*	*Cavigelli*	*CHC*	*BASF*	*Posner*	*Park*	*Klumper*	*Cox-Cherney*	*Hossard*	*Lesur-Domolin*	*Ponsio*	*Kravchenko*	*Gianessi (herbicide)*	*Gianessi (fungicide)*	*Gianessi (insecticide)*
Barley	30.0%	25.4%										18%			16%	
Beans dry white												16%		25%		
Beans coloured												16%		25%		
Canary seed												18%				
Canola	12.0%	49.6%						17.7%				18%		45%		
Chick peas												16%				
Corn for grain	18.0%		31.0%		17.8%	10.0%	14.5%	17.7%	32%	24%		18%	39%	20%		3%
Corn for Grain (Crop Protection)	18.0%		31.0%		17.8%	10.0%	14.5%	17.7%	32%	24%		18%	39%	20%		3%
Flaxseed	12.0%	21.8%										18%				
Lentils												16%				
Mustard seed												18%				
Oats		27.1%										18%				
Peas dry		32.9%										16%				
Rye all												18%				
Soybeans	12.0%		23.3%			10.0%	3.0%	17.7%				18%	52%	26%	19%	5%
Sugar beets												18%		29%	28%	23%
Sunflower seed	12.0%	45.8%										18%		16%		50%
Wheat, all excluding durum wheat	40.0%	23.3%	0.5%							43%		18%	29%	25%	19%	3%
Asparagus				55.0%							14.0%			55%	22%	67%
Beans				50.0%							14.0%					50%
Beets				56.0%							14.0%					
Broccoli				100.0%							14.0%			14%		80%

Brussels sprouts			100.0%		14.0%			
Cabbage			100.0%		14.0%		34%	64%
Carrots			100.0%		14.0%	48%	26%	50%
Cauliflower			100.0%		14.0%			
Celery			75.0%		14.0%	0%	39%	48%
Corn		31.0%	100.0%	17.8%	14.0%	25%	36%	25%
Cucumbers			100.0%		14.0%	66%	70%	34%
Garlic			100.0%		14.0%		50%	
Leeks			67.0%		14.0%			
Lettuce			100.0%		14.0%	13%	47%	50%
Dry onions			75.0%		14.0%		24%	22%
Other melons			90.0%		14.0%			
Parsley			6.0%		14.0%		33%	66%
Parsnips			100.0%		14.0%			
Peas			85.0%		14.0%	20%		50%
Pumpkins			100.0%		14.0%			
Shallots			80.0%		14.0%			
Spinach			80.0%		14.0%	50%	38%	
Squash and zucchinis			100.0%		14.0%			
Tomatoes	21.0%		100.0%		14.0%	23%	19%	53%
Peppers			100.0%		14.0%			
Radishes			90.0%		14.0%			
Rhubarb			44.0%		14.0%			
Rutabagas and turnips			100.0%		14.0%			
Watermelon			80.0%		14.0%		62%	
Apples	3.0%		100.0%		15.0%	15%	86%	95%
Apricots	3.0%		100.0%		15.0%			
Blueberries	3.0%		62.0%		15.0%	67%	63%	80%

Cherries sour	3.0%	75.0%	15.0%			76%	95%
Cherries sweet	3.0%	75.0%	15.0%			76%	95%
Cranberries	3.0%	70.0%	15.0%		50%	68%	60%
Grapes	3.0%	89.0%	15.0%		1%	95%	50%
Nectarines	3.0%	74.0%	15.0%				80%
Peaches	3.0%	70.0%	15.0%		11%	54%	100%
Pears	3.0%	100.0%	15.0%			99%	90%
Plums and prunes	3.0%	100.0%	15.0%			45%	
Raspberries	3.0%	90.0%	15.0%		0%	60%	50%
Saskatoon berries	3.0%		15.0%				
Strawberries	3.0%	100.0%	15.0%		30%	59%	50%
Potatoes				30%	32%	44%	37%