

# An Overview of the Canadian Agricultural Innovation System



Extended Version

## Agricultural Institute of Canada

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### An Overview of the Canadian Agricultural Innovation System

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## Agricultural Institute of Canada

*Informed · Credible · Current*

### Vision

Canadian agriculture is a global leader in stewardship of our land through science.

### Mission

For the Agricultural Institute of Canada to be Canada's Voice for Agricultural Research and Innovation.

Founded in 1920, the Agricultural Institute of Canada (AIC) is Canada's only organization whose sole focus is agricultural research and innovation with a mission to be its voice at the national level.

AIC's mandate is:

- Influence public policy;
- Disseminate information;
- Promote careers in agricultural research and innovation;
- Facilitate networking; and,
- Encourage international linkages.

For over ninety-five years, the Agricultural Institute of Canada (AIC) has responded to the needs of its members in serving the agricultural community, playing a central role as a source of credible information and comment for the Canadian agriculture and agri-food sector.

The Institute has established itself as one of Canada's foremost advocates for agricultural research and an important tool to facilitate the dissemination of agricultural research to academics and industry stakeholders.

Today's AIC represents a common voice for agricultural research and innovation.

We consult, work with our members and develop policies that benefit the agricultural innovation system.

*An Overview of the Canadian Agricultural Innovation System* provides a detailed description of Canada's agricultural research and innovation landscape, identifying its main strengths and contributing to finding appropriate solutions to emerging issues in the sector.

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## Summary

Canada's agricultural sector provides one in eight jobs, generating 6.6 % of the country's GDP.

Canada is the fifth-largest global exporter of agri-food products generating 5.7% of the total value of world food and agriculture exports.

From farmers and ranchers to food and beverage processors, retailers and consumers, Canada's rich and diverse agriculture and agri-food system plays a critical role in an economy increasingly dominated by manufacturing and service industries, generating \$113.8 billion – 6.6 % of Canada's GDP.

Canada's agricultural sector provides one in eight jobs in Canada, employing over 2.3 million people – one million more workers than those employed in the energy and renewable resources sector.

With a sparse population and a large supply of natural resources, our agricultural sector has continued to expand over the years, reporting a compound annual growth greater than that of the healthcare and life-science sector.

Canada is now the fifth-largest global exporter of agri-food products generating export sales of \$55 billion – 5.7% of the total value of world food and agriculture exports.

A rapidly-growing world population, rising income in developing countries and favourable global market trends are expected to raise demand for agricultural products worldwide, contributing to an estimated annual growth of 2% in Canada's agriculture trade by 2025.

Agricultural innovation is the key driver of economic growth in the sector, enabling greater competitiveness as well as opportunities to meet food security and sustainability goals in Canada and around the world.

Agricultural innovations have contributed enormously to the transformation of Canada's agriculture sector over the last 50 years, strengthening our competitive position internationally.

Yet, while investments in agriculture research continue to slow down and increases in land use are no longer available, technological competition grows from emerging agricultural export countries.

Unless we capitalize on our strong innovative potential, Canada's agricultural productivity gains will be unable to sustain momentum in today's changing global trade environment.

## FOCUS AREAS FOR GROWTH IN AGRICULTURAL RESEARCH AND INNOVATION

### Funding

High Canadian and global benefit-cost ratios for agricultural research – estimated to range from 10:1 to 20:1 – confirm that the productivity gains attributed to agriculture R&D is worth many times the value of its expenditures.

Very large marginal benefit-cost ratios may, however, reflect substantial and continued underinvestment in agriculture R&D, suggesting that it would likely have been profitable to have invested much more.

This has an enormous impact on Canada's agriculture where the public sector continues to be the largest source of funding for agriculture R&D. Furthermore, other key funders of agricultural research, particularly the private sector, also appear to either under-invest or decrease their investments in agriculture R&D due to low short-term returns on investment or insufficient incentives.

Total expenditures by the federal and provincial ministries of agriculture in support of the agriculture and agri-food sector as a whole have gradually declined over the past decade. The portion of this support going to producers has mostly been geared towards smoothing volatility and managing risk at the farm level rather than investing in variables affecting productivity growth such as the adoption of new technologies.

Budgetary expenditures specifically financing the Canadian agricultural innovation system, represented 0.046% of Canada's total GDP in 2015, ranking 7<sup>th</sup> worldwide and steadily declining over the past three decades.

In 2015-16, \$649.5 million of total federal Science and Technology (S&T) investment went through the federal ministry of agriculture toward agriculture and agri-food R&D. Both real AAFC and provincial R&D expenditures have demonstrated a slow downward trend from peak funding levels over the last two decades.

### Knowledge Creation, Dissemination and Adoption of Innovation

Despite ranking 8<sup>th</sup> worldwide in scientific production of agricultural research, Canada's number of patents has progressively dropped over the last decade.

Food processing companies are less innovative than other types of manufacturing enterprises, partially reducing their capacity to process domestic agricultural output and contributing to the country's US\$3.2 billion trade deficit for agri-food products.

While farmers and producers can benefit from new digital technologies, information and technical resources, the lack of a common analytics platform and rural broadband often prevents farmers and ranchers from realizing the full potential of large-scale research such as precision agriculture.

Industry associations and commodity groups have increasingly taken the leading role in extension activities with new dissemination channels and on-field training opportunities to facilitate stakeholders' understanding of technical knowledge. Nevertheless, most farmers still rely on their own experience and experimentation rather than third-party advice to implement a new technology or process.

Key funders of agricultural research appear to either under-invest or decrease their investments in agriculture R&D.

The lack of a common analytics platform and rural broadband often prevents farmers and producers from realizing the full potential of large-scale research.

## Human Capital

Skilled labour shortages in agriculture are potentially undermining Canada's research capacity, but may also be affecting other stages of the innovation continuum such as the farm-level adoption of research. Extension specialists and highly educated producers capable of understanding and transferring agricultural innovation are needed to ensure that research is adopted promptly on the ground.

As recently as 2014, the sector counted 26,400 unfilled jobs that reflected a cost of \$1.5 billion in lost revenues, with the estimated labour supply growth for highly-skilled occupations projected to be insufficient to meet future demand.

Enrollment in Canada's agricultural post-secondary programs has steadily increased at an annual average growth rate of 1.7% over the last two decades. The number of post-secondary agriculture graduates has also grown consistently at an average annual rate of 3.9%. These rates, however, remain insufficient to meet the future demand for skilled labour.

## MOVING FORWARD

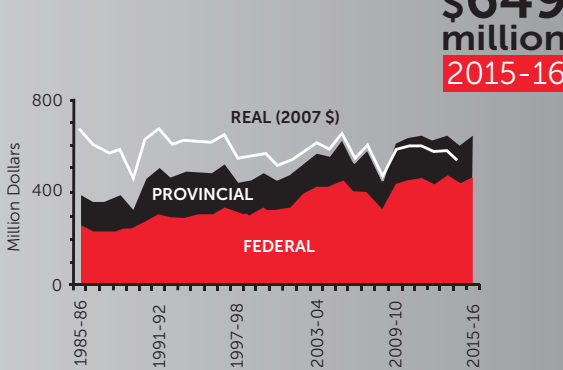
Our robust scientific base, broad network of stakeholders and multiple innovation hubs provide Canada's agricultural sector with valuable tools. Nevertheless, meeting the world market's growing demand in a sustainable manner requires:

- An inclusive demand-driven innovation system supported by a science-based policy framework, an enabling regulatory environment, and governance structures that promote continuous technological progress while encouraging the adoption of innovations at the farm level.
- A combination of funding mechanisms, including matching investment strategies, to suit the particular needs and characteristics of our sector and to ensure all types of research are adequately supported.
- An attractive climate for private investment in agriculture to increase the number of innovative companies willing to capitalize on our research capacity, stimulating Canada's competitiveness and enhancing job growth.
- Participatory research approaches that engage all stakeholders in research projects and knowledge transfer activities, ensuring that new knowledge and technologies respond effectively to end-users' needs.
- Guidance and career counselling information, investments in education through grants, scholarships and infrastructure, and Canada-wide strategies to raise the profile of agricultural innovation to help address human resource challenges in the sector.

The sector counted 26,400 unfilled jobs that reflected a cost to the sector of \$1.5 billion in lost revenues.

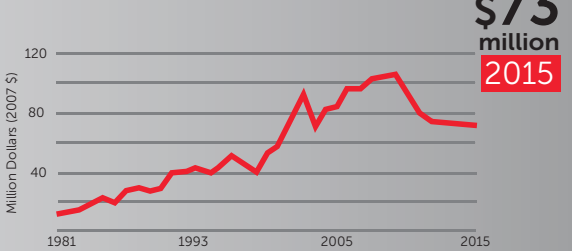
# Canada's Agricultural Research at a Glance

## Public Agriculture R&D Spending Provincial & Federal (AAFC Estimates) Primary Agriculture & Food Processing



Source: AAFC

## Private Agriculture R&D Spending Primary Agriculture



Source: Statistics Canada

<sup>1</sup> Agriculture only, Agriculture, forestry, fishing and hunting amounted \$83M

Investment

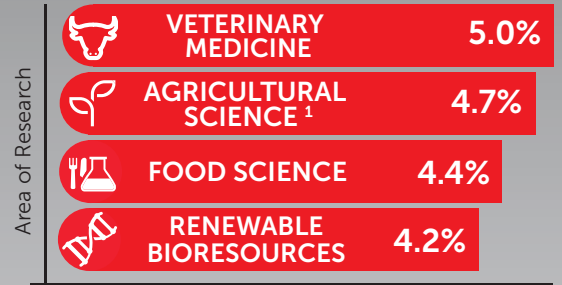
## Scientific Production

**6,878**  
academic  
papers  
published  
2014

**8<sup>th</sup>** place in  
scientific  
production of  
agricultural  
research  
**worldwide**

Sources: Science-Matrix, Statistic Canada

<sup>1</sup> Includes Agronomy, Agricultural Engineering, Irrigation, Weed and Pest Control, Agroforestry, Agricultural Economics & Policy, Plant Sciences, and Land Resource & Soil Science

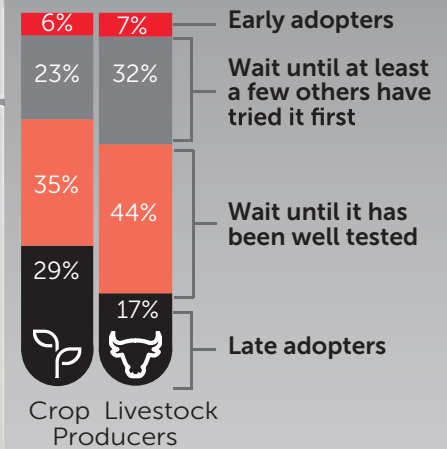


Canada's share at the World Level (%)

**29,937** students enrolled  
in agricultural programs  
2014-15

## Farm-Level Adoption

Speed of adoption



Agricultural innovations are more likely to be adopted by **large farms** with revenues of over one million dollars.

Source: AAFC

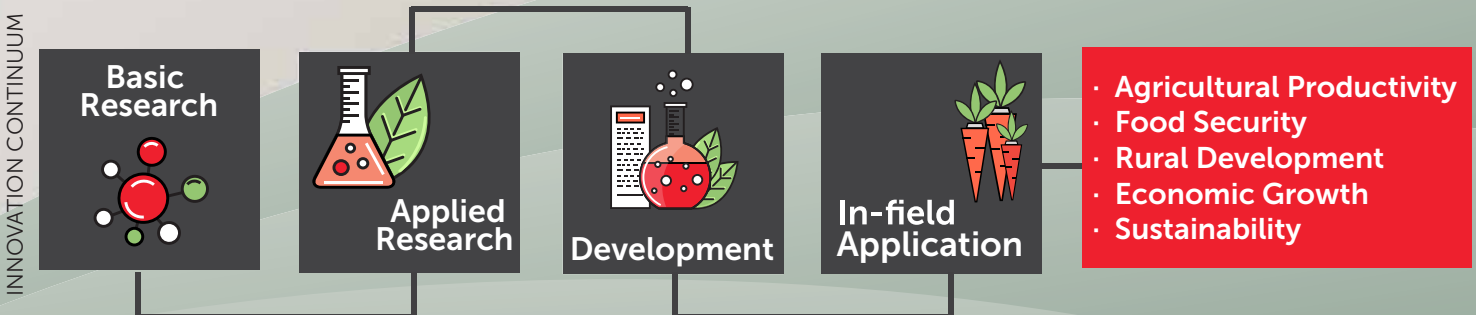
**48%** Canadian farms  
adopted  
agricultural  
innovations in  
2013

Source: AAFC

## Actors



## Why does agricultural research matter?





# A. Introduction

## A.1. The Agriculture and Agri-Food System in the Canadian Economy

From farmers and ranchers to food and beverage processors, retailers and consumers, the agriculture and agri-food system plays a critical role in an economy increasingly dominated by manufacturing and service industries, generating \$113.8 billion – 6.6% of Canada's GDP in 2017 (Statistics Canada, 2017).

Canada's agriculture and agri-food system provides one in eight jobs in Canada, employing over 2.3 million people in 2014 (AAFC, 2016) – one million more workers than those employed in the energy and renewable resources sector (ACEG, 2017).

With a sparse population and a large supply of natural resources, Canada's agricultural sector has continued to expand over the years to become a major producer of agricultural commodities worldwide. Canada is currently the fifth-largest global exporter of agri-food products generating export sales of \$55 billion – 5.7% of the total value of world food and agriculture exports (AAFC 2016, 2016b and FCC, 2016).

A strong history of production and a rich and diverse sector has made Canada the single largest global exporter of wheat, canola, and lentils (ACEG, 2017), and a major exporter of beef and pork (OECD, 2015).

While crop production is mostly concentrated in the Western Prairies, most milk production can be found in Eastern Canada, which also produces a larger variety of crops, including various fruits and vegetables. Hog, beef cattle and other red meat industries maintain a significant presence across Canada, particularly in Western Canada, Ontario and Québec.

From 2012 to 2015, the sector reported a strong compound annual growth rate of 2.7% – greater than both the energy and renewables and healthcare and life-science sectors. High crop yields in 2016

resulted in an even higher, 3.3% growth (Statistics Canada, 2017b) and as the global demand for Canadian agricultural products increases over the next decade, the Canadian agriculture sector is projected to expand further (AAFC, 2017).

## A.2. The Agricultural Innovation System

Agricultural innovations<sup>1</sup> such as new crop varieties, livestock breeds, nutrient management practices, tilling methods and farm machinery, as well as advancements in biotechnology, precision agriculture, communication and information technologies and alternative energy sources have significantly contributed to the transformation of the Canada's agriculture sector over the last 50 years.

With the world's population expected to reach 9 billion people by 2050, a large increase in production of all major crops, livestock and fisheries will be required to meet current and future needs for food, feed, fibre and fuel in Canada and globally. This growth relies on agricultural innovation to drive productivity gains and provide a basis for building a more globally competitive and sustainable economy.

Agricultural productivity growth demands continuous technological progress. Sustainable growth, however, requires a paradigm shift from the traditional supply-driven innovation model, to a more inclusive and participatory demand-driven Agricultural Innovation System<sup>2</sup> (AIS) that involves a broad range of actors who guide, support, create, transfer and adopt innovation (OECD, 2013). This dynamic network-based model requires continuous collaboration, strong stakeholder relationships, knowledge exchange and a supportive institutional, policy and governance environment.

Using an approach consistent with AIS, this document aims to describe the Canadian agricultural research landscape to help assess the impact of innovation in the sector.

<sup>1</sup> Innovation is the implementation of a new or improved product, marketing method, or organizational method in business practices, workplace organization or external relations (OECD, 2005). Agricultural innovation encompasses science and technology (S&T), research and development (R&D) and the adoption of scientific research outputs such as new production techniques or improved farming practices.

<sup>2</sup> The concept of innovation systems provides a framework to understand the process of innovation – from the lab to the marketplace – emphasizing how the interaction and relationships between multiple actors determines the overall performance, impact and scope of innovation processes. This conceptual framework has been increasingly used to understand the process of innovation in agriculture – from S&T and R&D to knowledge transfer and extension.

# B. Canadian Agricultural Research Landscape

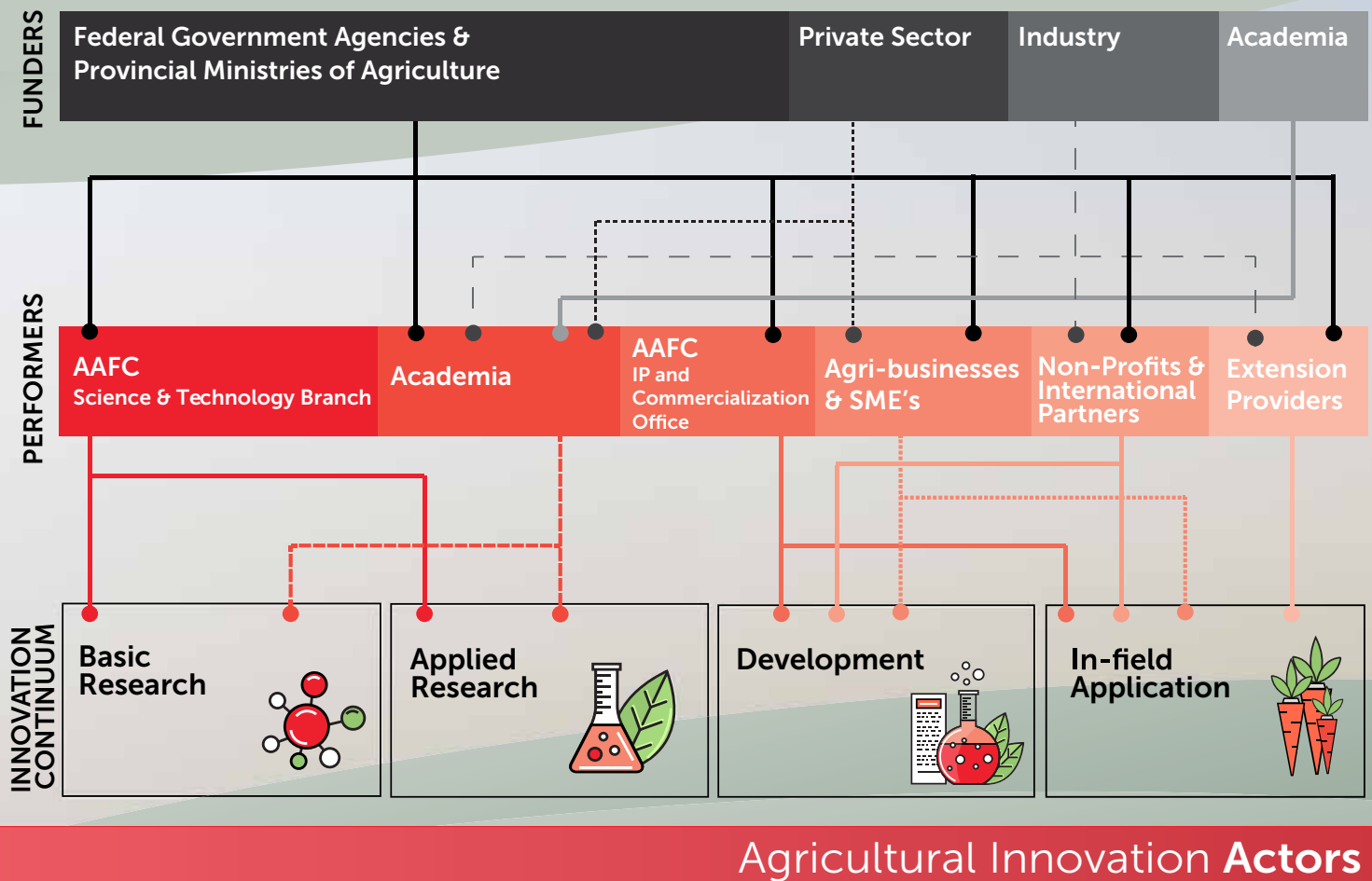


Image B.1. Agricultural Innovation Actors

## B.1. Structure of Agricultural Research in Canada

### B.1.1. Innovation Actors: Funders, Performers, Intermediaries and International Partners

Multiple stakeholders enable, create, fund, perform, implement, inform and disseminate innovation across the agriculture sector to meet the challenge of bringing new and relevant research to end-users.

Each stakeholder involved in the research value chain pursues a particular role within the system while interacting with other players in a complex and dynamic innovation process (Image B.1).

**Federal and provincial governments** are significant investors and performers of agricultural R&D and public extension, catalyzing partnerships across sectors as well as establishing policies and programs to support research and innovation activities.

Governments are also research performers who undertake a large portion of the scientific production in Canada and are responsible for significant capacity-building initiatives, particularly in infrastructure.

Provincial and territorial governments invest in and perform R&D activities in accordance with the differing structure and needs of their regional economies often through investment in post-secondary institutions and regional business R&D.

Agri-businesses and agri-entrepreneurs – **the private sector** – also play a dual role as funders and performers of agriculture R&D mostly geared towards applied research and commercialization.

Public-private partnerships (P3s) – where the private sector provides other actors, most notably post-secondary institutions, with infrastructure or resources to conduct research projects – have become an increasingly more popular investment vehicle in Canada.

The active participation of the private sector in agricultural research brings valuable opportunities for companies to increase productivity and competitiveness, specifically in areas that have a high potential for market returns such as biotechnology. Agri-businesses are also essential for the adoption of new science and technologies by end-users, a key stage within the innovation continuum.

**Industry groups** – commodity-specific and industry associations representing farmers, ranchers, and producers – help coordinate and direct funds for research efforts and act as intermediaries by supporting extension and knowledge transfer activities.

Although innovation is only one aspect of their overall mandate, some of the largest commodity groups have created national sector-specific, industry-led funding agencies to manage and direct funds for agricultural research. Collaboration between producers and the public and private sectors is encouraged through public-private-producer partnerships (P4s).

**Post-secondary education institutions** – universities, colleges, CEGEPs and polytechnics – are key suppliers of cutting-edge technical knowledge in agriculture, biosciences, food, nutrition and veterinary sciences. These institutions train highly qualified personnel (HQP) with the skills and knowledge required to conduct scientific research and to lead innovation processes. They also perform a broad spectrum of R&D and innovation activities ranging from early stage theoretical and basic research to applied science and experimental development.

Academic R&D is funded through a variety of sources including federal and provincial governments, the private sector and industry partners, with agri-businesses often seeking strategic relationships with universities to develop new technologies and to attract new R&D talent.

**Extension and advisory service providers** are the driving forces behind agricultural growth and

productivity, facilitating the transfer of new scientific discoveries from the lab to producers in the field.

Extension encompasses a wide range of services and intermediary actors in both the public and private sectors.

Regulated by the provincial institutes of agrology are professional agrologists who provide quality agricultural services and research-based advice supporting the development of farm operations.

Other intermediaries include input manufacturers and distributors, agro-marketing, private consulting enterprises and cooperatives, with industry-led extension initiatives also sharing relevant scientific information through various dissemination channels such as websites or print publications.

**Non-profits and international partners** create valuable opportunities for international cooperation with multi-national companies and post-secondary institutions working to solve global challenges.

Non-profit business incubators and accelerators also provide infrastructure, business services, technical advice and continuous support to help agri-entrepreneurs grow their businesses, supporting innovation processes and facilitating the commercialization of new technologies.

The federal government has worked to facilitate cross-border researcher mobility as a founding member of the Consultative Group on International Agricultural Research (CGIAR) and through provision of support to the International Development Research Centre (IDRC), incentivizing international knowledge sharing to address global food and agricultural issues in developing countries.

From 1995 to 2012, the Canada-CGIAR Linkage Fund (CCLF) provided grants to post-secondary institutions to promote the use of Canadian technologies and specialized expertise. Examples of these institutions are Université Laval and the Universities of Guelph, Saskatchewan, British Columbia, Alberta, Manitoba, Ottawa, New Brunswick, the Nova Scotia Agricultural College and the Plant Biotechnology Institute (CGIAR, 2014).

## B.1.2. Policy and Governance

Through the *Federal Science, Technology and Innovation (ST&I) Strategy*, the Government of Canada sets out strategic direction for the development of innovation activities and various research initiatives across all sectors of the economy including agriculture.

Updated in 2014, the current *ST&I Strategy* introduced new actions to develop, attract and retain high-quality personnel, strengthen core investments in capacity-building and stimulate business innovation.

Under this strategy, agriculture was added to the environment research priority putting a particular emphasis on technological development, genomic research and manufacturing.

Innovation, Science and Economic Development Canada (ISED) is responsible for setting Canada's Innovation Agenda and the Ministry of Science oversees and supports scientific research and integration of evidence-based policy-making.

Advising the ISED is the Science, Technology and Innovation Council (STIC), who provides advice and benchmarking reports on ST&I performance every two years.

Agriculture and Agri-Food Canada (AAFC) leads federal efforts in the growth and development of the agriculture sector, with the National Research Council of Canada (NRC) and the federal research funding organizations (NSERC, SSHRC, CIHR, Genome Canada and CFI) playing an important supporting role for R&D and innovation.

As a shared federal-provincial-territorial jurisdiction and a key sector for regional economic development, agriculture is among the top priority issues on the provincial policy agendas.

Provincial ministries of agriculture work alongside the federal government to set direction for their own agricultural innovation systems and to provide support for post-secondary institutions, agri-business, industry groups, extension service providers and regional research centres concentrating on provincial agricultural research priorities.

*Growing Forward 2* (GF2), the current five-year policy framework for the agriculture and agri-food industry developed and implemented by AAFC and governed by a joint federal-provincial-territorial (FPT) agreement, guides innovation and collaborative initiatives in the sector (Image B.2).

Under GF2, the main federal initiative to support the agricultural innovation system is *AgriInnovation*, a program that addresses all three stages of the innovation continuum: research, technology transfer and commercialization.

### Research priority setting

The Environment and Agriculture section of the Government of Canada's *ST&I Strategy* outlines seven sub-areas of particular focus to agriculture including water security, biotechnology, aquaculture, food and food systems, and climate change research.

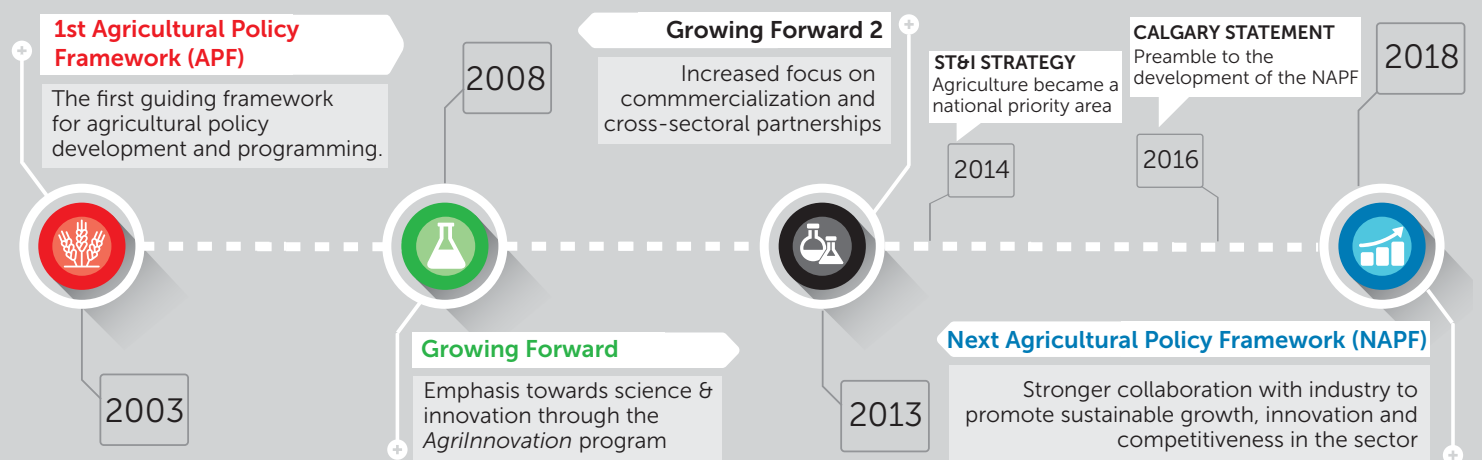


Image B.2. Canadian Agricultural Policies (2003-2018)




Strategic Objectives 	Commodity-Focused Areas 
<p>Increase agricultural productivity</p> <p>Enhance environmental performance</p> <p>Improve attributes for food and non-food uses</p> <p>Address threats to the value chain</p>	<p>Cereals and Pulses</p> <p>Oilseeds</p> <p>Horticulture</p> <p>Forage and Beef</p> <p>Dairy, Pork, Poultry and other Livestock</p> <p>Agri-Food</p> <p>Bioproducts</p>
Cross-cutting Agricultural Challenges 	
<p>Biodiversity and Bioresources</p> <p>Agro-Ecosystem and Health</p>	

Table B.1. AAFC Science: Strategic Objectives and Areas of Focus

Increased adoption and knowledge of sustainable farming practices, and the promotion of innovation are also identified as key strategies to contribute to a world-leading agricultural sector in the *2016-2019 Federal Sustainable Development Strategy (FSDS)* – the third whole-of-government plan that sets out Canada’s sustainable development priorities, goals and actions.

In line with the FSDS and the *ST&I Strategy*, four main strategic objectives guide AAFC’s in-house science activities through its Science and Technology Branch (STB) in 20 research stations across the country namely: increasing agricultural productivity, enhancing environmental performance, improving attributes for food and non-food uses, and addressing threats to the value chain. Seven commodity-focused areas and two cross-cutting agricultural challenges guide in-house AAFC’s science activities to meet these objectives (Table B.1).

Agricultural industry groups also have a significant impact on the strategic direction of public research and the innovation agenda through their own advocacy efforts and by sharing their views at the House of Commons Standing Committee on Agriculture and Agri-Food and the Senate Standing Committee on Agriculture and Forestry.

They also participate in various consultative and networking mechanisms at both the provincial and national levels that bring policy makers and industry stakeholders together to provide strategic guidance for agricultural research program development and priority setting.

Launched in 2003, the Value Chain Roundtables (VCRTs), commodity-based working groups facilitated by AAFC, have worked to successfully bring stakeholders together at the national level to set long-term national strategies in a variety of areas, including the coordination of research efforts reflecting sector-specific needs.

At the provincial level, various consultative bodies help stakeholders define research priorities. For example, the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) created the Research Advisory Network (ORAN) – a network of advisory bodies comprised of expert panels, analysts, research program directors, researchers and other stakeholders that help guide agricultural research program development and priority setting on key areas ranging from agricultural policy and rural development to environmental sustainability.

Post-secondary education institutions, largely autonomous and responsible for setting their own research priorities, seek to build strength in areas of importance to Canada taking into account provincial and federal research priorities.

## B.2. Investments in Agricultural Innovation

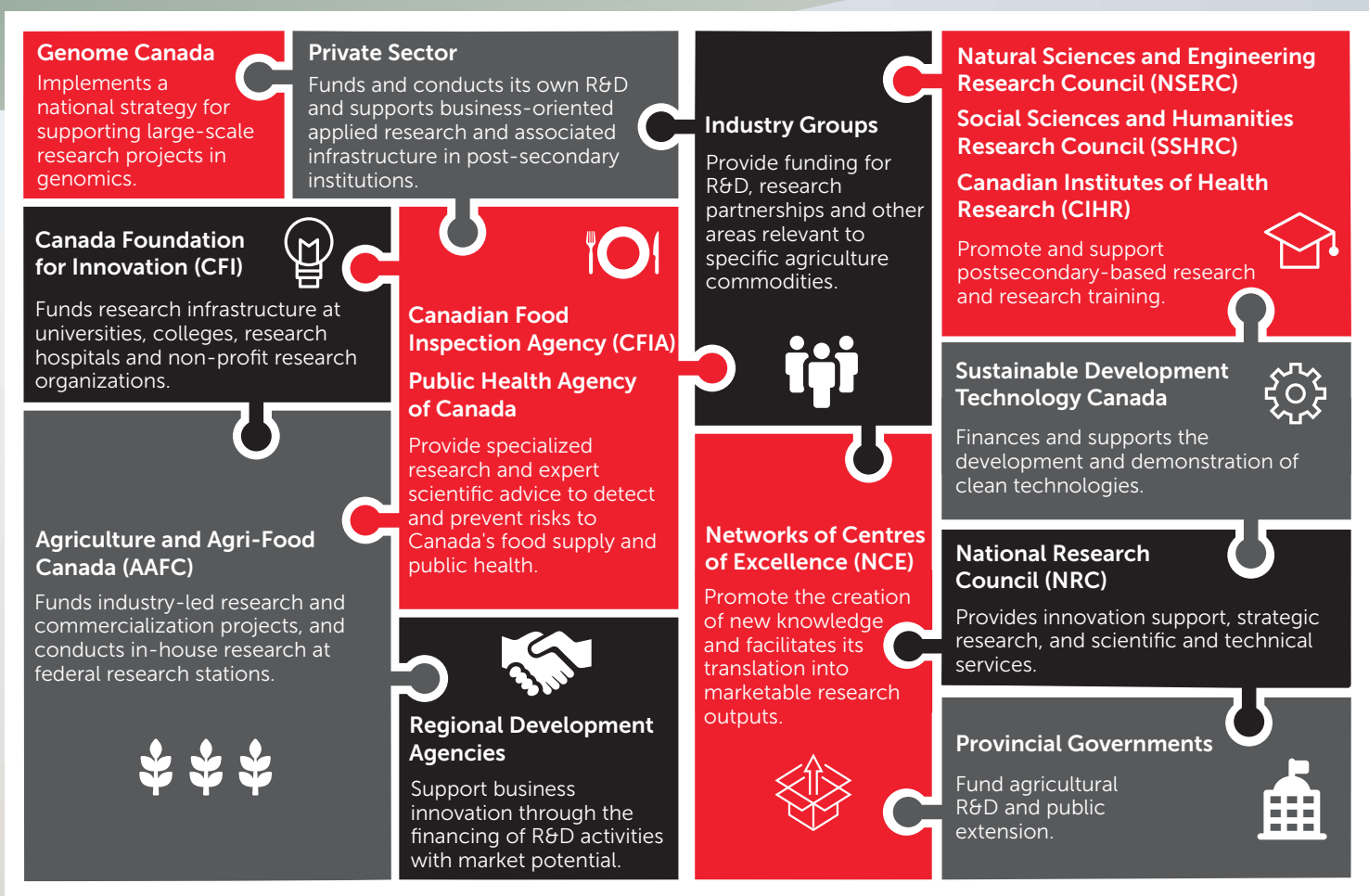
### B.2.1. Funding Mechanisms for Agricultural R&D and Innovation

The public sector supports the direct costs of research, infrastructure, uptake of talent, commercialization activities and the development of R&D networks through a variety of funding programs at the federal and provincial levels, as well as indirectly through tax incentives for business investment in R&D.

Multiple federal departments and agencies finance agricultural innovation (Image B.3) including, but not limited to:

- NSERC, SSHRC and CIHR provide targeted funding for post-secondary institutions, researchers and students to fund innovation, build high-quality Canadian-based research capacity and facilitate the creation of cross-sectoral R&D networks.

- The Canada Foundation for Innovation (CFI) – the federal government’s principal mechanism for funding research infrastructure – invests in the tools, equipment and facilities used by researchers to create new knowledge and technologies, assist companies to innovate, and train the next generation of entrepreneurial students.
- The National Research Council Canada (NRC) – supports business innovation through commercial and industrial R&D and innovation services in many areas of research, including crop resources and bio-products.
- Regional Development Agencies promote business innovation through the financing of R&D activities with commercial market potential in key sectors such as agri-food (Ex. FedNor).



## Funding mechanisms for agricultural research

Image B.3. Funding mechanisms for agricultural research

		STREAM	SUB-STREAM	MAXIMUM FUNDING AMOUNT
INNOVATION CONTINUUM	Inception	Industry-led Research and Development Stream	Agri-Science Cluster	Up to a maximum of \$20M
	Pre-commercialization		Agri-Science Project	Up to a maximum of \$5M
	Commercialization	Enabling Commercialization and Adoption Stream		Up to a maximum of \$10 million, and \$2 million for commercial demonstration projects

Table B.2. *AgrilInnovation* funding by streams

- AAFC – directs federal government expenditure on agricultural research through AAFC research scientists’ salaries, federal research stations and funding for research projects conducted directly by the STB.

AAFC distributes funding through two main streams in the *AgrilInnovation* program (Table B.2).

The *Industry-led Research and Development Stream* places a greater emphasis on industry-driven R&D investments. Within this stream, the *Agri-Science Clusters* bring together scientific expertise from industry, academia and government to address multiple priorities in the science plans of fourteen commodity sectors (Table B.3). Single research projects or smaller sets of projects are also funded within this stream through the *Agri-Science Project*.

In addition to *AgrilInnovation* funding, *GF2 Cost-Shared Programs* allow federal government funds to be matched by provincial and territorial contributions on a 60/40 basis. This structure provides flexibility to design and deliver programs that address regional needs in innovation, competitiveness and industry capacity.

Provincial governments finance direct costs of post-secondary institutions and regional research centres including expenditures associated with R&D activities such as human capital, infrastructure and commercialization.

Producer association check-off schemes or mandatory levies as well as cross-sectoral partnerships are also common sources of funding for agricultural innovation in areas relevant to specific commodities.

The National Beef Check-off, for example, is a critical source of revenue to fund research in the Canadian

cattle and beef sector. The research allocation of the national check-off is managed by the Beef Cattle Research Council (BCRC) and is used to leverage additional industry and government funding including AAFC’s Beef Cattle Industry Science Cluster.

Business R&D investment and performance is a decisive factor in the creation of a competitive and innovative environment in all sectors of the Canadian economy (OECD, 2015b).

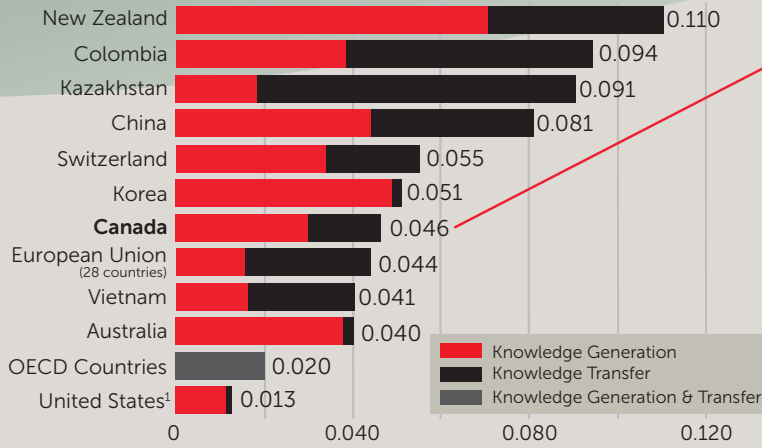
In the agriculture sector, the private sector has an important role to play, funding its own R&D, and often supports business-oriented applied research and associated infrastructure in post-secondary institutions.

	<b>CROP RESEARCH</b>
<b>Organic Cluster</b>	· Organic Federation of Canada
<b>Pulse Cluster</b>	· Pulse Canada
<b>Wheat Cluster</b>	· Western Grains Research Foundation
<b>Barley Cluster</b>	· Alberta Barley Commission
<b>Canola Cluster</b>	· Canola Council of Canada
<b>Horticulture Cluster</b>	· Canadian Horticulture Council
<b>Ornamental Cluster</b>	· Canadian Ornamental Horticulture Alliance
<b>Field Crops Genetics Improvement Cluster</b>	· Canadian Field Crop Research Alliance
	<b>LIVESTOCK RESEARCH</b>
<b>Beef Cluster</b>	· Beef Cattle Research Council
<b>Dairy Cluster</b>	· Dairy Farmers of Canada
<b>Poultry Cluster</b>	· Canadian Poultry Research Council
<b>Swine Cluster</b>	· Swine Innovation Porc
	<b>BIOTECHNOLOGY</b>
<b>Bioproducts Cluster</b>	· Bioindustrial Innovation Centre
	<b>FOOD PROCESSING</b>
<b>Agri-Food Innovation and Prosperity Cluster</b>	· Canadian Food Innovators

Table B.3. AAFC Agri-Science Clusters and Industry Partners

# Funding Trends in Agriculture R&D

## Expenditures in Agriculture R&D and Extension % of Total Country GDP, 2015<sup>1</sup>

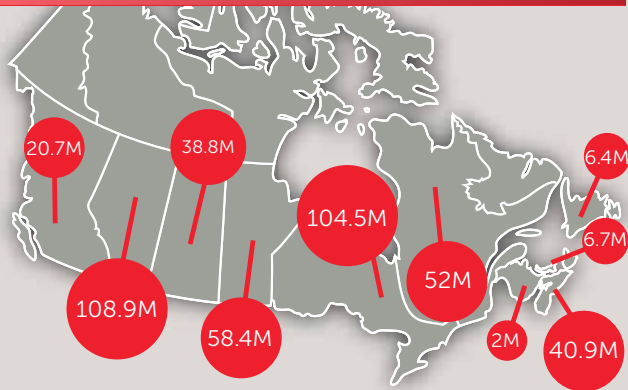


0.046% of GDP

0.030% Knowledge Generation  
0.016% Knowledge Transfer

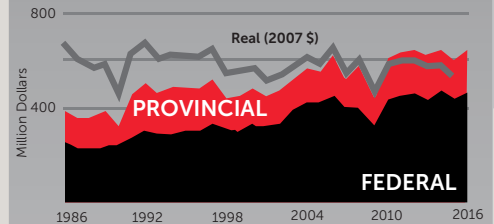
Source: OECD, Producer and Consumer Support Database (2016)

## Provincial Expenditures in Agriculture R&D and Extension 2015-2016<sup>4</sup>



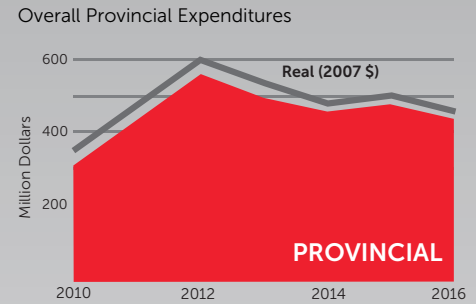
Source: Provincial Public Accounts and financial statements of provincial ministries of agriculture, 2015-2016.

## Public Research Spending in Support of the Agriculture & Agri-Food Sector<sup>2</sup> Primary Agriculture & Food Processing AAFC's Estimates



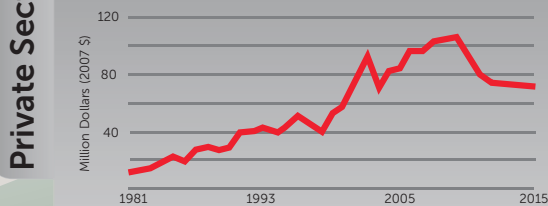
Source: AAFC Estimates. Chart extracted from *An Overview of the Canadian Agriculture and Agri-Food System*, AAFC 2016.

## Public Provincial Expenditures in Agricultural Research, Education & Extension<sup>3</sup> Overall Provincial Expenditures



Sources: Provincial Public Accounts and financial statements of provincial ministries of agriculture, 2010-2016.

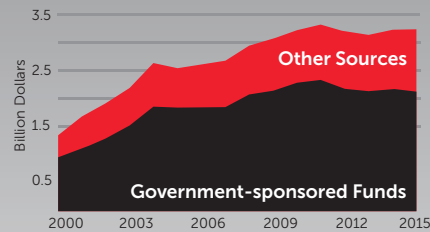
## Real Private Sector R&D Expenditures<sup>5</sup> Primary Agriculture



Source: Statistics Canada

## Academia

## Total sponsored expenditures (all fields)<sup>6</sup> supporting research at post-secondary institutions with agricultural programs



Source: Canadian Association of University Business Officers, *Financial Information of Universities and Colleges*, Report 31, 2000-2015

Image B.4. Funding Trends in Agriculture R&D

1 Agricultural knowledge generation includes budgetary expenditure to finance agricultural research (institutes, grants) and gene banks. Agricultural knowledge transfer includes agricultural education and generic training and extension services provided to farmers. The U.S.A. ranked 18<sup>th</sup> among 33 countries and the European Union.

2 AAFC Estimates. Federal research values correspond to operating, capital and program expenditures.

3 AIC Estimates. Sources for provincial expenditures: Provincial Public Accounts and financial statements of provincial ministries of agriculture, 2010-2016. Real values (2007 \$) based on StatCan Price Indexes.

4 For a more detailed description of the data and sources used in this map, see the References section at the end of this report.

5 Data includes all R&D expenditures (intramural) made by private industry regardless of whether the sources of funds were self-financing but does not include investments from the agricultural input sector.

6 Post-secondary institutions with agricultural programs included in this chart are members of the Canadian Faculties of Agriculture and Veterinary Medicine. Government-sponsored funds include federal, provincial, municipal, intra-provincial and foreign governments. Other sources of funding include donations, non-government grants and contracts, investment, sale of services and products, and miscellaneous. None of the listed institutions allocated resources from tuition and other fees towards research.



## B.2.2. Funding Trends in Agriculture R&D

### Public Sector

Total expenditures by the federal and provincial ministries of agriculture in support of the agriculture and agri-food sector as a whole (including payments to producers, agricultural general services, research and innovation) have gradually declined over the past decade, both in dollars and as a share of the agriculture GDP (Chart B.1).

For the 2015-16 fiscal year, total government expenditures reached \$5.3 billion, a \$2.8 billion reduction relative to 2007-08 figures (AAFC 2008, 2016). As a share of the agricultural GDP, government expenditures were estimated to be 26% in 2015-16, a reduction of about 10 percentage points compared to 2007-08 estimates.

Budgetary expenditures<sup>3</sup> financing the Canadian agricultural innovation system, including the costs associated with knowledge generation and transfer

activities, represented 0.046% of Canada's total GDP in 2015, ranking 7<sup>th</sup> worldwide (Image B.4). More than half of these expenditures were allocated to agricultural knowledge generation – R&D spending on applied research in the primary agricultural sector.

Canada's investment in agricultural research and innovation as a portion of total country GDP has steadily declined by almost 0.080 percentage points over the past three decades, mirroring a similar downward trend in the OECD average (Chart B.2). China, the world's second largest agricultural exporter and a key competitor in scientific production of agricultural research, has maintained a significant upward trend in agriculture R&D investment over the last decade, accounting for 0.081% of the country's GDP in 2015 (OECD, 2016). Image B.4 summarizes Canada's funding trends in agricultural research.

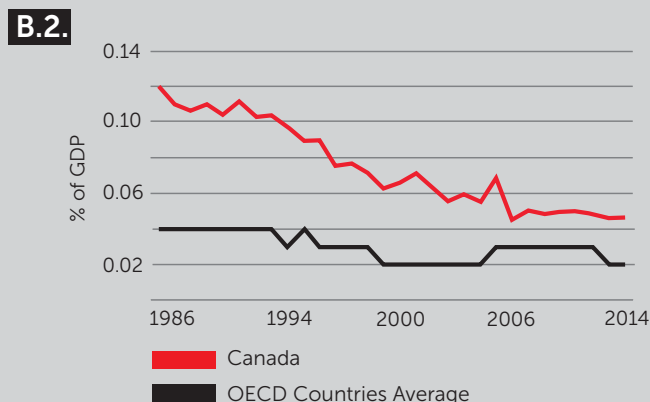
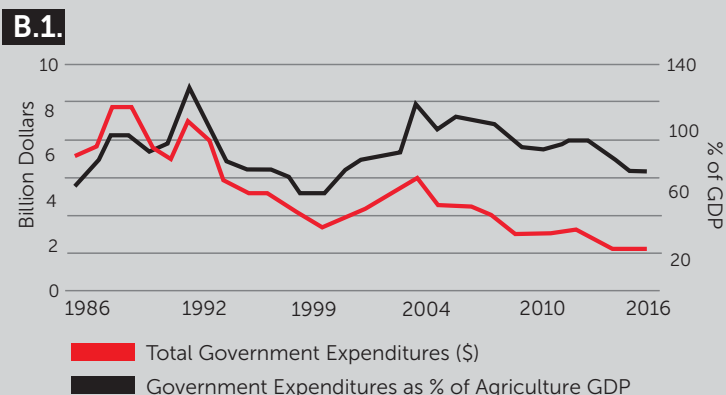


Chart B.1. Total government expenditures in support of the agriculture and agri-food sector as a share of agriculture GDP, 1985-2016  
Source: AAFC

Chart B.2. Public expenditure for the agricultural knowledge and innovation system, as a share of total GDP, 1986-2015. Source: OECD

### Federal Government

In 2015-16, the total federal expenditure across all departments, including AAFC, in agriculture S&T was \$705 million, a decrease of 11.7% from 2010. About 70% of this investment was allocated to in-house S&T – intramural S&T activities managed and carried out primarily by federal government agencies and departments (Statistics Canada, 2017c).

Extramural expenditures – grants, contributions, fellowships and contracts to other performers of agriculture<sup>4</sup> S&T such as post-secondary institutions,

the private sector, non-profits and provincial governments – amounted to \$238 million in 2016, a decrease of 24% from 2010 (Statistics Canada, 2017c).

Based on AAFC's annual estimates, in 2015-16, \$649.5 million of total federal S&T investment went through the federal ministry of agriculture toward agriculture and agri-food R&D (primary agriculture and food manufacturing R&D) – an increase from \$643 million in 2014-15 (AAFC, 2016).

<sup>3</sup> Budgetary expenditures include real budgetary payments and other transfers which do not require actual monetary disbursements (tax credits, interest rates or input prices) provided through policies that support producers collectively (General Services Support Estimate).

<sup>4</sup> This category includes: scientific research on chemical fertilizers, biocides, biological pest control and the mechanization of agriculture as well as research on the impact of scientific activities in the field of developing food productivity and technology (NABS Nomenclature).

Under AAFC's current agricultural policy framework GF2, a five-year budget of \$698 million was allocated to *AgriInnovation*, representing 61% of the total funds supporting the three programs under GF2 aimed to generate market-based economic growth in the agricultural sector (AAFC, 2016c).

Despite these changes and after accounting for inflation, AAFC estimates for real agriculture R&D expenditures (2007\$) have demonstrated a slow downward trend from peak funding levels in the mid-1990s (Image B.4).

The three federal research funders – NSERC, SSHRC and CIHR – collectively provided \$14 million in 2014-15 to support academic research and training in agriculture. To enable this research, CFI committed \$8 million to fund infrastructure for agricultural research projects in 2014-15 .

The National Research Council (NRC) reported total expenditures of \$36.6 million for Aquatic and Crop Research Development (ACRD) in 2014-15 with approximately 10% of these expenses being funded through earned revenues (\$3.5M) – one-third of which has been generated through industry partnerships since 2012 (NRC, 2016).

### ***Provincial Ministries of Agriculture***

In 2015-16, overall reported expenditures by provincial ministries of agriculture – including capital, program, and operating expenses supporting both agricultural research and its associated activities (education and extension) – collectively accounted for \$440 million (Image B.4). Similar to federal expenditures, real provincial estimates for agriculture R&D expenditures (2007\$) have also shown a slow decline after having reached a peak in 2012 (Image B.4).

Models and levels of agriculture R&D investment vary considerably from province to province due to regional differences in agricultural production across Canada. Considering average provincial expenditures in agriculture R&D and extension from 2010 to 2016, Alberta, Ontario, Québec, Manitoba and Nova Scotia are the top funders of Canada's agricultural research and innovation.

In Manitoba, Québec and New Brunswick, key investments are geared towards agricultural education and training, extension services, technical assistance and rural development programs that

provide significant spin-off benefits from provincial expenditures in human capital and capacity-building of producer communities to drive regional economic development.

In Ontario and Nova Scotia, a focus on targeted investments arising from strategic partnerships has worked to increase the knowledge base and mobilization efforts needed to facilitate the deployment of agricultural innovations. By seeking synergies with regional key players, particularly post-secondary institutions, these provinces have increasingly optimized agriculture R&D resources while maximizing stakeholder engagement.

A focus on commodity-targeted investments in provinces like Alberta has also offered valuable opportunities to extract the maximum potential from regional advantages and resources. While other provinces (Saskatchewan, Newfoundland and Labrador and Prince Edward Island) have adopted a more comprehensive government directed funding strategy to ensure the distribution of resources across the entire continuum of innovation – from research and development to knowledge transfer and technical support.

The production of high-value added technology and innovation is strongly linked to the ability to stimulate entrepreneurship and encourage agri-business competitiveness and productivity. The agricultural innovation system cannot insulate itself from business processes, therefore, funding models for innovation should simultaneously work to drive the development of the agriculture sector along with increased scientific production.

British Columbia's Ministry of Agriculture has, for example, integrated agriculture R&D programs into the Business Development stream, increasing public investments in agricultural innovation in 2016 by almost 80% relative to 2013.

### ***Private Sector***

Business R&D performance is a critical factor in the creation of a competitive and innovative environment in all sectors of the Canadian economy. Nevertheless, existing data on Canada's BERD – Business Enterprise Expenditures on Research and Development – shows that the private sector is not investing in R&D at a globally competitive level.

Canada’s private sector invested less in R&D as a share of GDP than many other advanced economies, falling from 18<sup>th</sup> position in 2006 to 25<sup>th</sup> in 2014 (OECD, 2014). In the 2016-17 World Economic Forum’s Competitiveness Survey, Canada ranked 29<sup>th</sup> in BERD (World Economic Forum, 2017).

While the BERD-to-GDP ratio for all sectors of the economy in OECD countries increased from 1.53% to 1.61% between 2007 and 2013, Canada’s ratio fell from 1.06% to 0.85% (Statistics Canada, 2017d).

Despite the introduction of intellectual property protection on new crop varieties in 1980 and an important increase in business spending between 1998 and 2002, private-sector R&D investment in the Canadian agriculture sector has slowed in recent years (Image B.4). In 2015, agri-businesses<sup>5</sup> in Canada spent \$212 million<sup>6</sup> on in-house R&D, down from \$290 million in 2009 (Statistics Canada, 2016).

Real private-sector spending on primary agriculture R&D amounted to \$74.2 million in 2013, down from a peak of \$102 million in 2008 (AAFC, 2015). In 2015, however, only 35% of total agricultural private-sector in-house R&D expenditures were invested in primary agriculture (Statistics Canada, 2016).

As for food processing sub-sector, real private-sector R&D expenditures reached \$125.9 million in 2014, averaging \$139.7 million between 2001 and 2014 – an increase of 34% from the 1981-2000 period (AAFC, 2016).

According to the latest data available, however, private-sector R&D intensity in the food processing industry – the ratios of the sub-sector’s BERD and output (GDP) – averaged about 0.6% from 1995-2006, a significantly low value relative to other Canadian manufacturing industries (i.e. Pharmaceuticals, 26.1%), and falling behind major developed countries such as U.S. and Japan (OECD, 2011).

Furthermore, the underdevelopment of Canada’s food processing sub-sector has partly reduced its capacity to process domestic agricultural output and has contributed to the country’s US\$3.2 billion trade deficit for agri-food products (ACEG, 2017).

## Academia

Research and development taking place in an academic setting is primarily supported by various public funding sources. Universities depend on this funding as Canadian higher education business models prevent post-secondary institutions from allocating tuition and other academic fees to fund research and development projects.

Despite notably improving research capacity and enhancing the learning environment, the revenue resulting from government contributions, however, may not be sufficient to actually meet the associated – direct and indirect – costs of further academic research activity (CAUBO, 2015).

Increased efforts to pursue greater revenue diversification from a wide range of new actors from the private and non-profit sectors and a focus on new business activities – non-government grants and contracts, donations, sales of services and products, investment income, and royalties arising from the use of institution owned rights or properties – have resulted in a growth of five percentage points in the non-public sector’s contribution to finance research at Canada’s post-secondary institutions with agricultural programs<sup>7</sup> from 2000 to 2015 (Chart B.3).

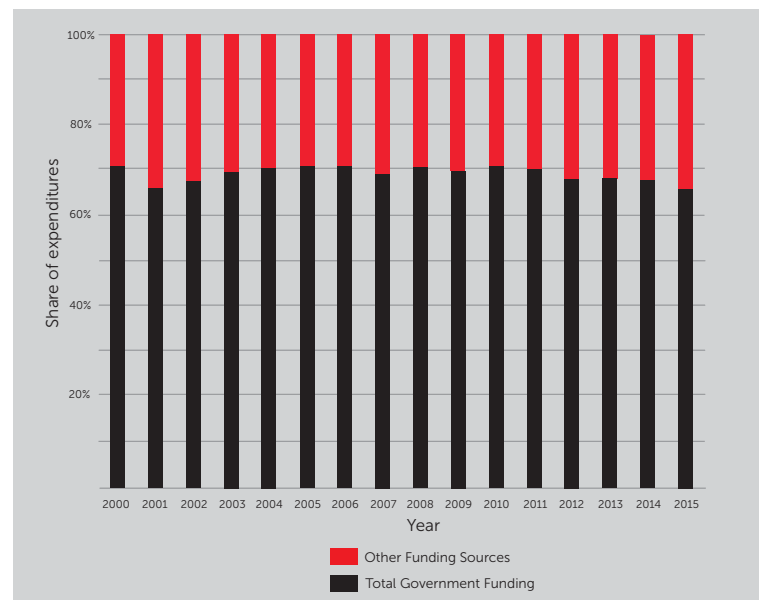


Chart B.3. Share of total research funding by governments and other sources at post-secondary institutions with agricultural programs from 2000 to 2015. Source: CAUBO, Financial Information of Universities and Colleges 2000-2015.

<sup>5</sup> North American Industry Classification System

<sup>6</sup> Current dollars

<sup>7</sup> Members of the Canadian Faculties of agriculture and Veterinary Medicine

## B.2.3. Human Capital

### ***Production of Highly Qualified Personnel (HQP)<sup>8</sup>***

From highly-skilled technical workers to world-class researchers, the agricultural innovation system relies on human capital to drive increased productivity growth and scientific development in the sector.

With a strong history as a key contributor to the advancement of the sector dating back to the foundation of agricultural societies over two centuries ago, agricultural education is essential to produce the highly qualified personnel (HPQ) required to support and manage innovation on the ground.

Today's highly competitive environment and more capital intensive agricultural practices require farm operators equipped with broad knowledge in business management, technology, and agricultural sciences (Statistics Canada, 2017e).

The following in-house data analysis is derived from Statistics Canada figures on Canadian post-secondary enrolments and graduates.<sup>8</sup>

In 2015, there were 29,937 students<sup>9</sup> enrolled in Agriculture, Natural Resources and Conservation degree programs at Canadian universities and colleges: 23,868 undergraduate and college students, and 5,151 graduate students – representing only 1.4% of total students in all post-secondary programs across Canada.

Enrollment in Canada's agriculture programs<sup>10</sup> has steadily increased over the last two decades at an annual average growth rate of 1.7% – a percentage change of 48% over the last 20 years. Ontario (34%), Québec (20%), British Columbia (14%) and Alberta (13%) account for the highest share of students enrolled in 2015.

With 49% of overall female participation, Ph.D. students in the agriculture and natural resources fields in 2015 represented only 2.8% of total students enrolled in all doctoral level programs in Canada, almost doubling since 1992.

In 2013, the Canadian Faculties of Agriculture and Veterinary Medicine noted a 50% rise in post-graduate international enrolment (CFAVM, 2013). By 2015, international students, both female and male, accounted for almost half (46%) of total agriculture Ph.D. enrolments.

In 2014, 8,880 students graduated from agriculture programs across the country – 1.8% of the total number of post-secondary graduates in all fields. Ontario accounted for the highest share of agricultural graduates (36%), followed by British Columbia and Québec (both 17%) (Chart B.4).

Similarly, the number of post-secondary agriculture graduates has grown consistently at an average annual rate of 3.9%, reflecting an overall percentage change of 132% between 1992 and 2014.

According to the latest data, 201 new doctorates<sup>11</sup> graduated from agricultural programs in 2014 – 3.7% of total doctoral-level graduates in Canada.

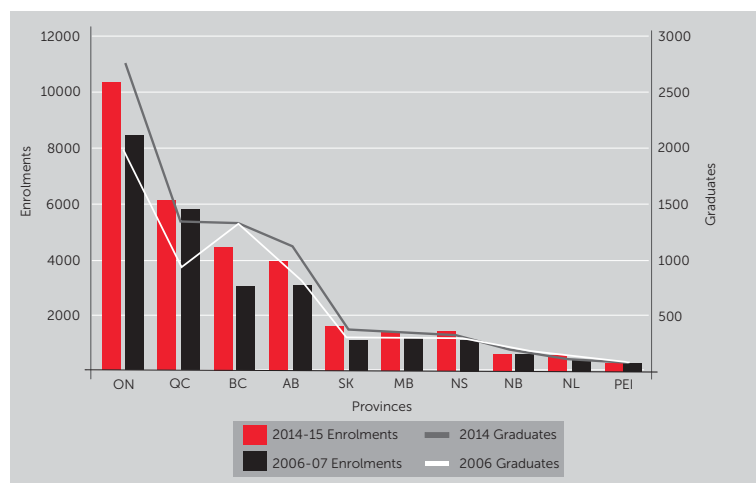


Chart B.4. Postsecondary enrolments and graduates in Agriculture, Natural Resources and Conservation programs by province, 2006-07 and 2013-14. Source: Statistics Canada, Table 477-0019 and 477-0020.

### ***Labour Force Deployment***

Labour shortages in Canada's agriculture sector as a whole pose a critical challenge in meeting production targets arising from stronger demand for Canadian agricultural products. As recently as 2014, the sector counted 26,400 unfilled jobs that reflected a cost to the sector of \$1.5 billion in lost revenues (CAHRC, 2016).

<sup>8</sup> In-house data analysis of Statistics Canada Tables 477-0019 and 477-0020.

<sup>9</sup> Including vocational, special or auditor, college, undergraduate and graduate students.

<sup>10</sup> Agriculture, Natural Resources and Conservation degree programs at Canadian universities and colleges.

<sup>11</sup> Third-cycle education, based on the Pan-Canadian Student Classification of Education.

While agricultural labour requirements will likely rise drastically by 2025 to match productivity demands, the size of the domestic agricultural workforce is expected to further contract, resulting in a major labour gap<sup>12</sup> of approximately 113,800 workers (CAHRC, 2016).

Canada's supply-managed sectors – dairy, poultry and eggs producers – have not reported the same labour shortages affecting the agriculture sector as a whole. CAHRC's last employer survey however indicated that these groups report a skill shortage. An analysis of the food processing industry also reported that firms face obstacles to innovation due to highly-skilled labour shortages (AAFC, 2015).

Although highly-skilled occupations – from biological technologists and technicians to agricultural consultants and extension specialists – tend to attract a larger number of young workers, the estimated

labour supply growth for this segment is also projected to be insufficient to meet future demand.

Over 10,000 people currently work in professional agricultural jobs related to natural and applied sciences<sup>13</sup>, including both research scientists and technical support staff (Statistics Canada, 2016b).

A 6.2% share of total scientific and technical personnel in all federal departments and agencies work in AAFC research centres across Canada with 1,629 research scientists and technicians performing agriculture R&D – a reduction of more than three hundred staff compared to 2012-13 (Statistics Canada, 2017f).

In the private sector, the latest data indicates 2,607 full-time personnel engaged in agriculture R&D activities<sup>14</sup> (Statistics Canada, 2016), 60% less than those in 2008 and representing only 1.9% of the total BERD labour force in all sectors of the economy.

## Agrology in Canada

Largely unique to Canada, the term "agrology" refers to a wide range of activities ranging from university teaching and agricultural innovation to consulting and advisory services. This science is based on an in-depth knowledge of the agriculture and agri-food system, environment, and economy.

In most Canadian provinces, agrology practice is a fully regulated profession. Each provincial institute of agrologists has its own regulator and registration requirements for both agricultural technologists and agrologists – highly-skilled science-based professionals who responsibly transfer knowledge and conduct research.

Provincial institutes of agrologists have also been instrumental in promoting careers in agriculture, driving up their membership numbers up to 9,786 professional agrologists (P.Ag.) across Canada (Agrologists Canada, 2017). Ongoing outreach efforts include branch scholarships and targeted presentations for high-school students to engage youth in agricultural science and research.

### *International Collaboration*

In 2015-2016, the International Development Research Centre (IDRC) allocated \$62.1 million – over 30% of its total research program expenses – to fund the direct costs of agricultural research projects worldwide (IDRC, 2016).

AAFC engages in global scientific cooperation with exporting countries and international non-profit organizations to build research networks and promote knowledge exchange.

In 2014, approximately 200 participants from about 20 countries also contributed to agricultural research projects in Canada through AAFC Foreign Research Participant Program – a program that provides foreign scientists with an opportunity to contribute to research conducted at federal research centres.

Over almost three decades, Canada has been particularly engaged in continuous scientific cooperation with China. Between 2006 and 2014,

<sup>12</sup> Labour gap: the difference between how many workers employers would like to hire (labour demand), and how many domestic workers are available to work (labour supply) (CAHRC, 2016).

<sup>13</sup> Physical science professionals, life science professionals and civil, mechanical, electrical and chemical engineers.

<sup>14</sup> Primary agriculture and food manufacturing R&D.

AAFC hosted more than 200 PhD students and over 100 visiting scientists at federal research centres, resulting in more than 1,000 co-authored publications with Chinese researchers.

With nine sponsored conferences and 37 research fellowships granted to Canadian researchers, the OECD Co-operative Research Programme has also played a key role in the promotion of international collaboration in agricultural research. Since 1979, this program has contributed to strengthening networking among agricultural researchers from OECD countries.

#### B.2.4. Knowledge Infrastructure

Agricultural innovation hubs – regional concentrations of state-of-the-art infrastructure and expertise – stimulate the creation and exchange of knowledge among multiple actors and bring together multidisciplinary expertise and resources needed to advance Canada’s agriculture sector.

The distribution of major agricultural research centres and facilities across Canada is outlined in images B.5 and B.6 according to their institutional setting and areas of research.

Federal and regional research centres as well as post-secondary institutions play a prominent role in research production with major research hubs in crop, livestock, and biotechnology found in Edmonton (AB), Guelph (ON), Halifax (NS), Québec (QC), Saskatoon (SK), Vancouver (BC) and Winnipeg (MB).

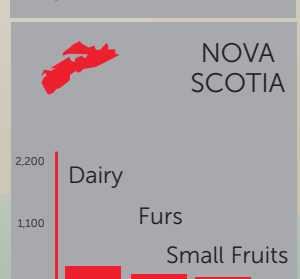
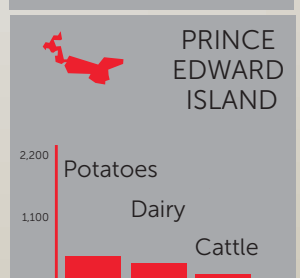
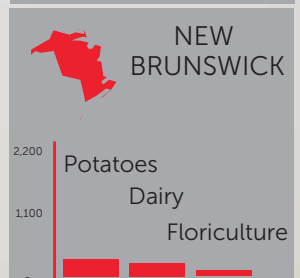
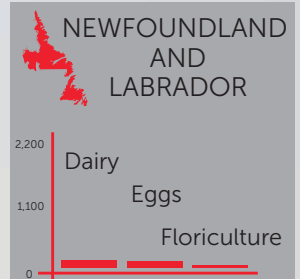
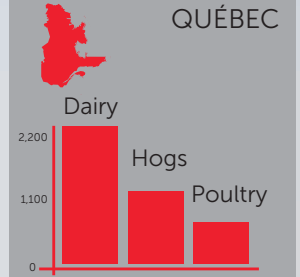
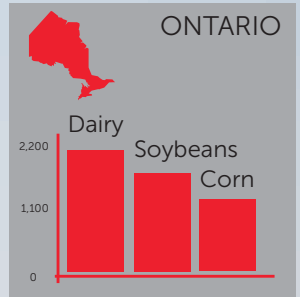
AAFC currently operates 20 agricultural research centres across the country. The last decade has seen the closure of seven AAFC research centres (Doern, 2016), however, the 2016 Federal Budget has committed to provide \$41.5 million, starting in 2016-17, to modernize and repair selected existing AAFC and CFIA research stations in British Columbia, Alberta, Saskatchewan, Ontario and Québec.

The federal government’s 2017 Budget – *Building a Strong Middle Class* – announced the development of a new federal Science Infrastructure Strategy, including a review of existing spending on federal science infrastructure such as federal laboratories and testing facilities. The 2017 Federal Budget also offered targeted investments of \$80 million on a cash basis over 5 years starting 2017-18 to replace the Sidney Centre for Plant Health (Sidney, BC).

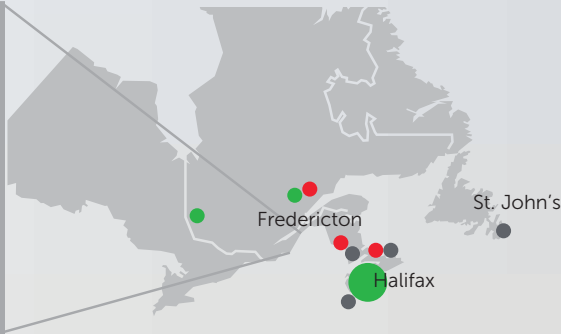
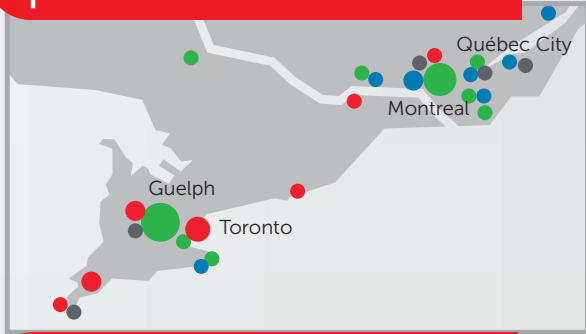
# Distribution and scope of major agricultural research facilities Eastern Canada



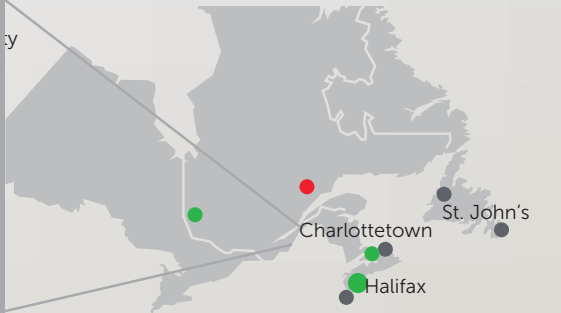
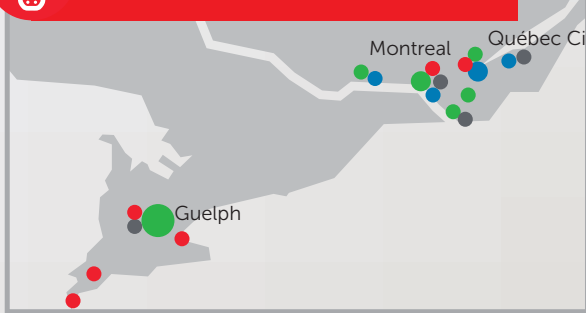
PROVINCIAL PRODUCTION <sup>1</sup>



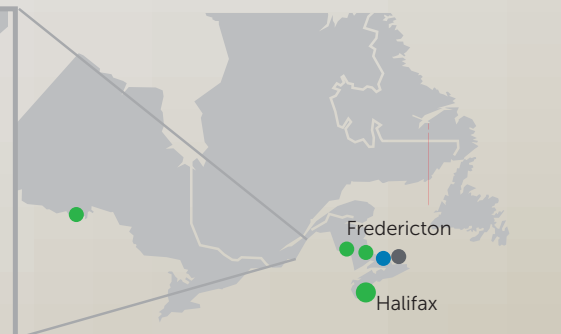
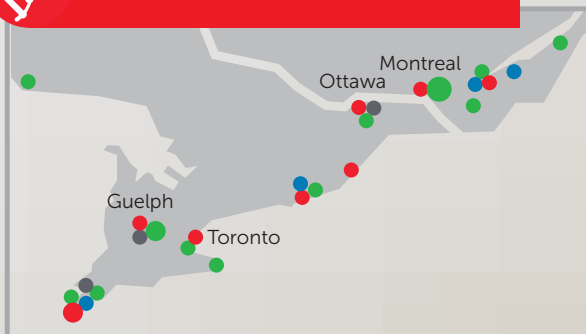
## CROP RESEARCH



## LIVESTOCK RESEARCH



## BIOTECHNOLOGY



- Federal & Provincial Governments
- Post-secondary Institutions
- Private Sector
- Non-Profit & Partnerships



The size of each city's circle is proportional to the concentration of major research centres, institutes and facilities.

<sup>1</sup>Statistics Canada - 2016 Farm Cash Receipts (Annual, dollars x 1,000)

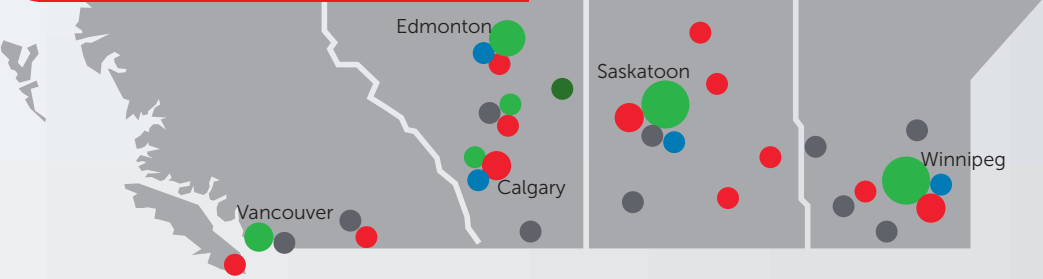
Image B.5. Knowledge infrastructure - Eastern Canada

# Distribution and scope of major agricultural research facilities

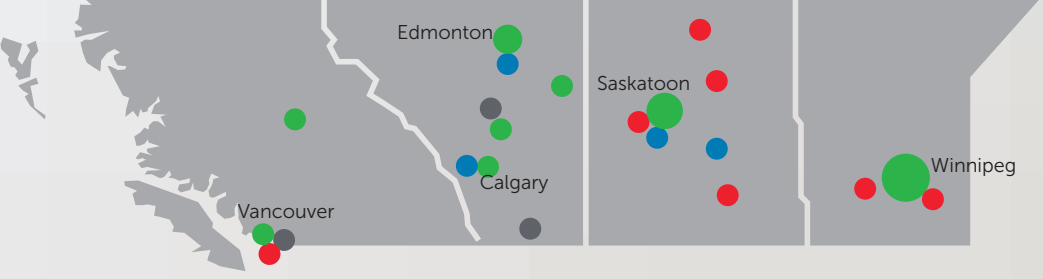
## Western Canada



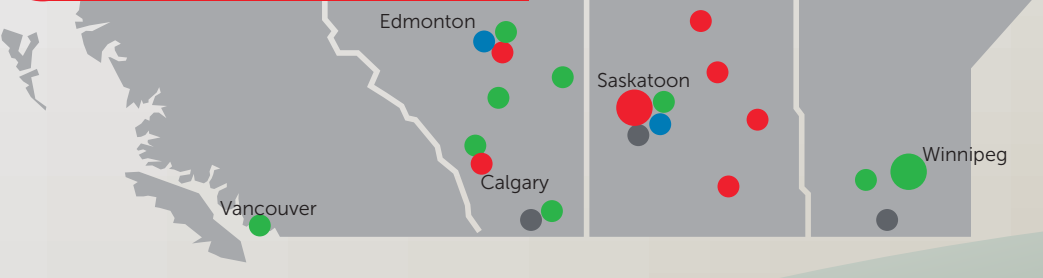
### CROP RESEARCH



### LIVESTOCK RESEARCH



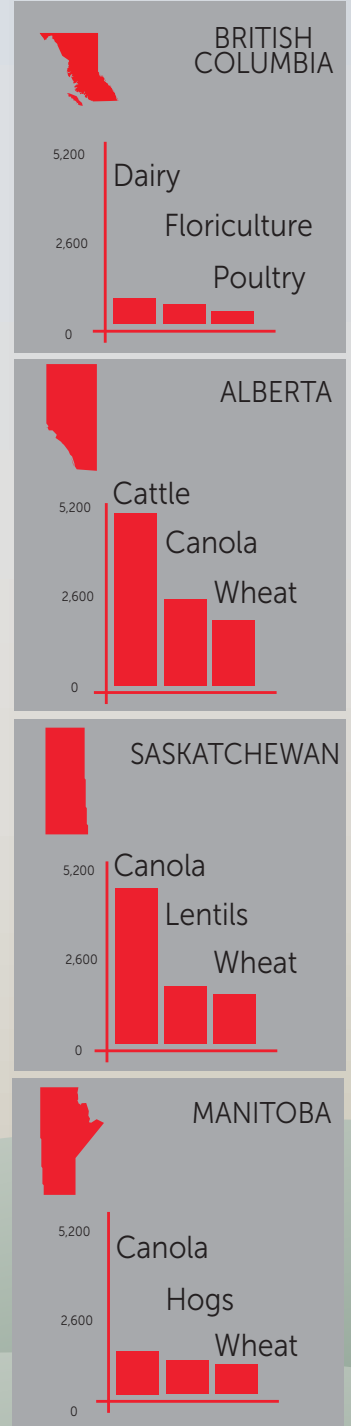
### BIOTECHNOLOGY



- Federal & Provincial Governments
- Post-secondary Institutions
- Private Sector
- Non-Profit & Partnerships

The size of each city's circle is proportional to the concentration of major research centres, institutes and facilities.

PROVINCIAL PRODUCTION <sup>1</sup>



<sup>1</sup>Statistics Canada - 2016 Farm Cash Receipts (Annual, dollars x 1,000)

Image B.6. Knowledge infrastructure - Western Canada



## B.3. Dissemination of Agricultural Research

### B.3.1. Trends in Scientific Production: Quantity and Quality of Canadian Research Publications

#### Volume

Canada ranks 8<sup>th</sup> worldwide in scientific production of agricultural research<sup>15</sup> between 1997 and 2014, generating 90,606 academic papers<sup>16</sup>, demonstrating a marked growth of 64% in papers published over the course of this period (Science Metrix, 2015).

Agricultural science<sup>17</sup> accounts for the largest share of Canada's scientific production in all fields of agricultural research. Veterinary science, however, reports one of the highest scientific production levels at the international level, with Canada ranking fourth worldwide (Science Metrix, 2015).

In the same reporting period, all post-secondary education institutions combined produced the vast

majority of scientific publications, accounting for 73% of agricultural research production in Canada, followed by federal government departments and agencies (21%) (Image B.7).

At the organization level, AAFC leads in Canadian agricultural scientific production, followed by the University of Guelph, and the Universities of Saskatchewan, Alberta and British Columbia, together making up the top-five leading organizations in the production agricultural research in Canada, with the University of Alberta more than doubling its scientific production over this seventeen year period (Chart B.5).

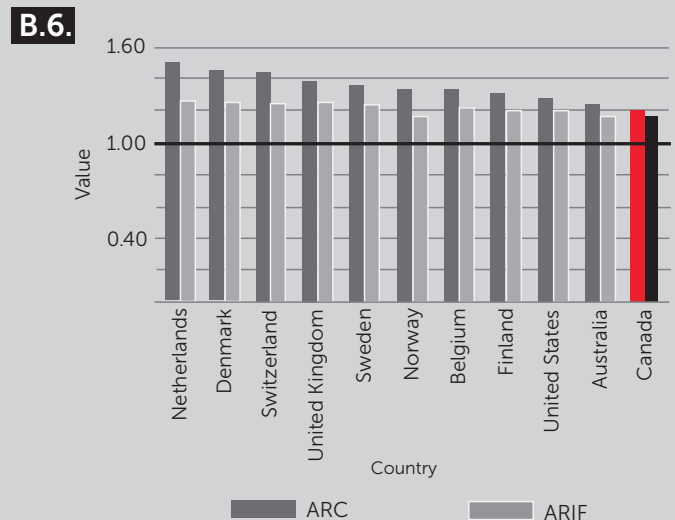
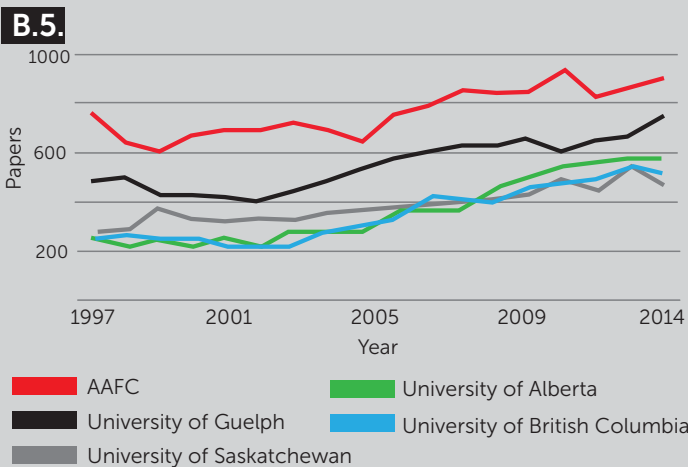


Chart B.5. Trends in scientific production of Canada's top 5 most publishing organizations in agricultural research, number of papers (1997-2014) Source: Computed by Science-Metrix using the Web of Science database (Thomson Reuters).

Chart B.6. Canada's ARC and ARIF scores compared to top 10 leading countries in scientific impact of agricultural research (1997-2014) Source: Computed by Science-Metrix using the Web of Science database (Thomson Reuters).

<sup>15</sup> Agricultural research includes the following subfields: agricultural science (agronomy, agricultural engineering, irrigation, weed and pest control, agroforestry, agricultural economics & policy, plant sciences, and land resource & soil science), veterinary sciences (animal welfare), food sciences (cereals, dietetics, etc.), renewable bioresources (mostly biofuels) and aquaculture.

<sup>16</sup> Papers indexed in the Scopus database.

<sup>17</sup> Agricultural sciences includes: agronomy, agricultural engineering, irrigation, weed and pest control, agroforestry, agricultural economics & policy, plant sciences, and land resource & soil sciences

## Impact

The average of relative citations (ARC)<sup>18</sup> provides a clear picture of the scientific impact of a country's agricultural research. An ARC above 1.0 shows that a particular entity – a country or institution – is more cited than the average world research in the same field.

From 1997-2014, Canada registered an average ARC of 1.19 (Chart B.6), ranking 16<sup>th</sup> internationally (Science-Metrix, 2015).

In its average relative impact factor (ARIF)<sup>19</sup>, Canada ranked 8<sup>th</sup> tying with Norway among top publishing countries worldwide with an ARIF score of 1.16 – improving by one position internationally since 2010.

At the sub-field level, Canada's scientific outputs in veterinary medicine scored the highest ARIF and ARC values indicating a major impact on of scientific performance in this area compared to renewable bioresources, food science and agricultural science (Chart B.7).

## Specialization

The specialization index (SI) measures the intensity of research or concentration of a country or institution in agricultural research relative to the world. An SI value above 1.0 implies that an entity is specialized relative to the world (Picard-Aitken & Côté, 2010).

In 2014, Canada ranked 21<sup>st</sup> out of 35 countries with an SI value of 1.03, indicating slightly specialized scientific production in agricultural research. This represents a drop from 2003 levels when Canada ranked 14<sup>th</sup> in this category (Science-Metrix, 2015).

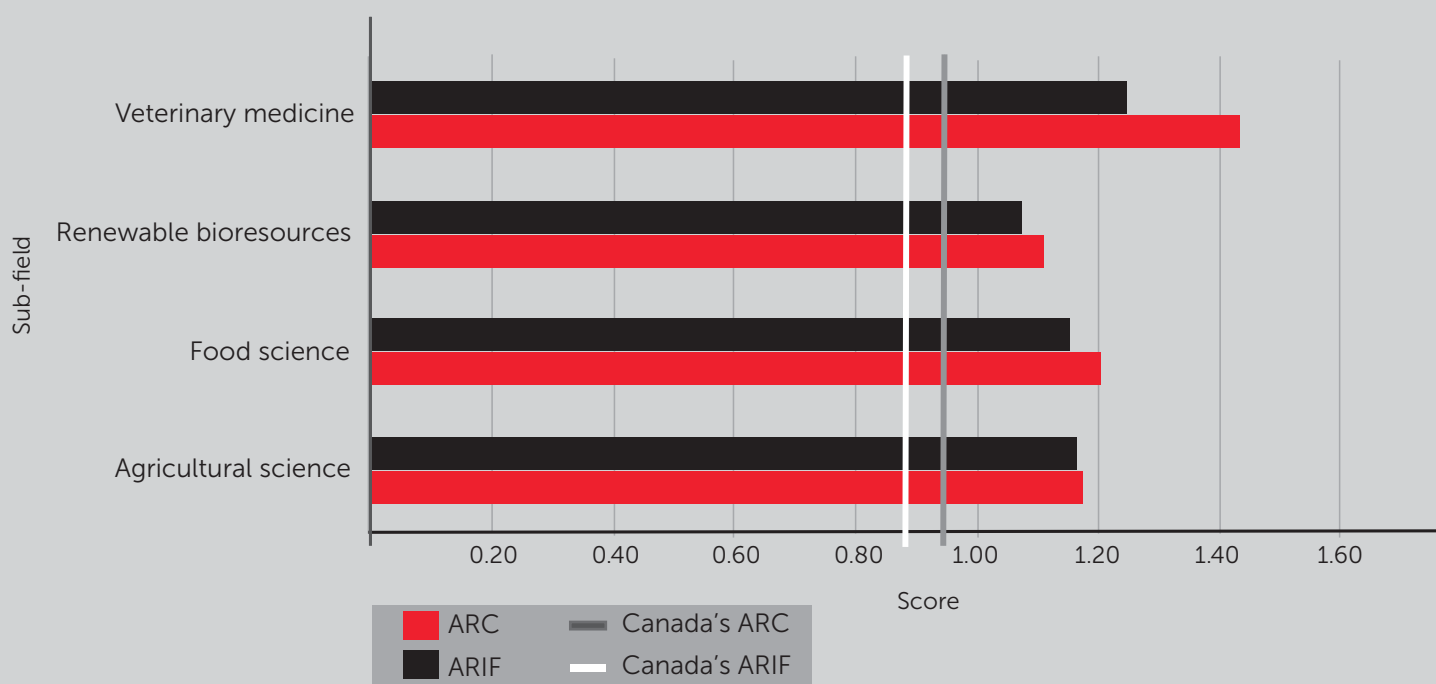


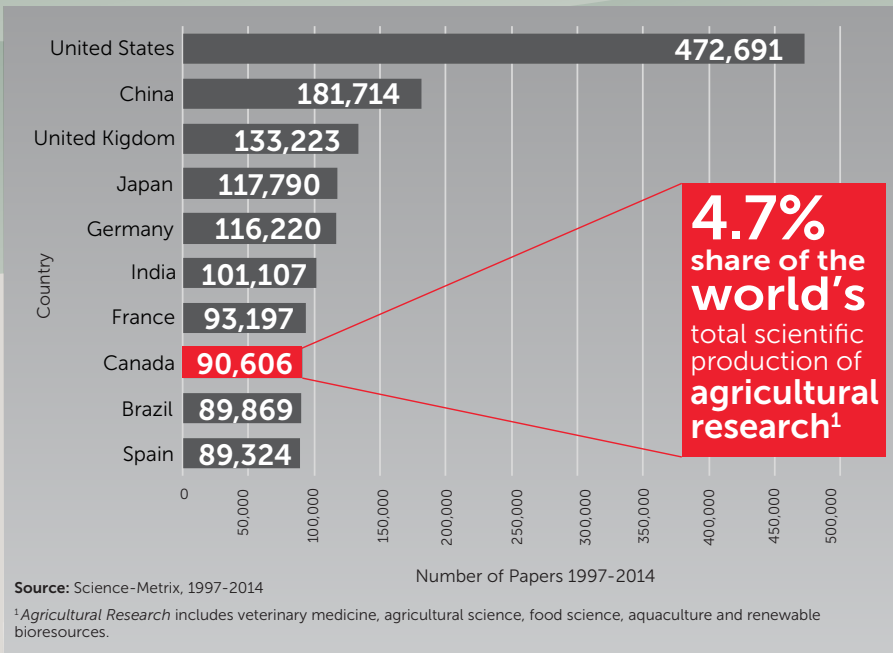
Chart B.7. Trends in impact of scientific production in agricultural research by sub-field, Canada (1997-2014). Source: Computed by Science-Metrix using the Web of Science database (Thomson Reuters)

Note: Data for renewable bioresources covers 1997-2012 only.

<sup>18</sup> The average of relative citations (ARC) measures the impact of research conducted by a country or institution based on the average number of citations its papers received relative to the average number of citations received by world papers.

<sup>19</sup> The average of relative impact factors (ARIF) is a quality indicator that identifies the expected scientific impact of papers produced in a particular country based on the impact of the journals in which the papers were published. The impact of those journals is measured by the number of citations each receives relative to the number of papers it publishes. An ARIF value above 1.0 implies that a country's papers have more impact than the world average in a given research area (CCA, 2011).

# Scientific Production in Agricultural Research



## Top 5 Publishing Institutions in Agricultural Research

- AAFC
- U of Guelph
- U of Saskatchewan
- U of Alberta
- U of British Columbia

Source: Science-Metrix

## Scientific Production

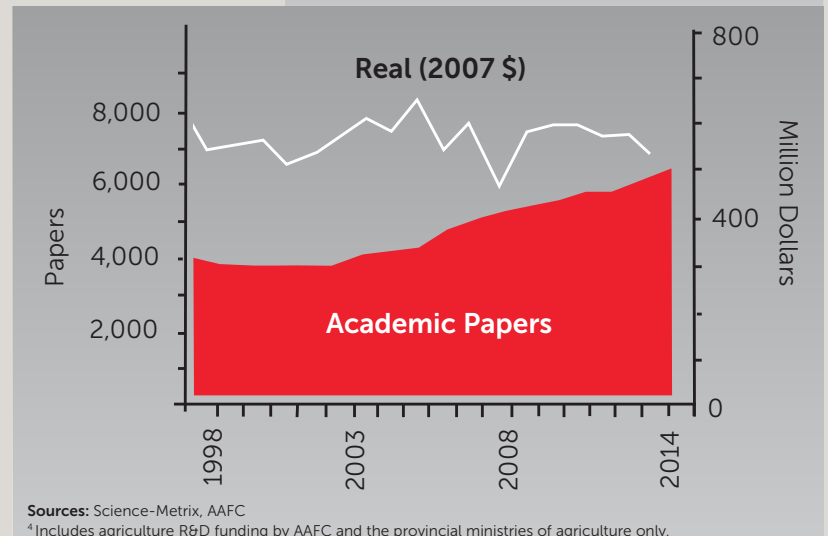
**16<sup>th</sup>** place in **scientific impact<sup>2</sup>** of agricultural research worldwide

Source: Science-Metrix  
<sup>2</sup> Based on Canada's average of relative citations (ARC) score (2014).

**21<sup>st</sup>** place in **level of specialization<sup>3</sup>** in agricultural research worldwide

Source: Science-Metrix  
<sup>3</sup> Based on Canada's specialization index (SI) score (2014).

## Scientific Production and Public Agriculture R&D Spending<sup>4</sup>



## Who are the key performers of agricultural research?

### Share of Canada's Scientific Production in Agriculture by Sector

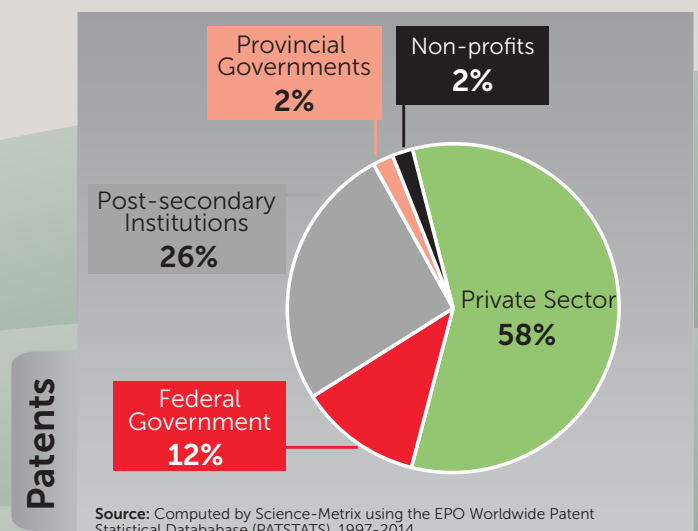
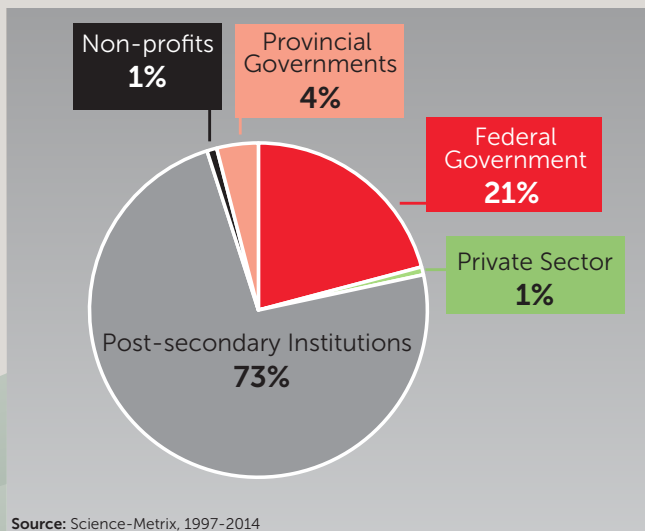


Image B.7. Canada's scientific production in agricultural research

### B.3.2. Knowledge Management and Commercialization of Agricultural Research

Intellectual property rights (IPR) affect nearly every step of the research process, from initial development to the sharing of results with other researchers.

Increased private sector participation and a greater focus on commercialization over the last two decades have gradually transformed agricultural research, particularly applied research, from a public good into a tradeable product protected by patents and other forms of IPR.

#### **Patents**

Patents provide an important mechanism for research dissemination. They require full public disclosure of research and encourage partnerships between academia, industry groups and the private sector, helping to more efficiently commercialize research into marketable products, protect investments and generate revenue for further innovations.

Since 1999, Canadian inventors have filed 371 patents<sup>20</sup> through the Patent Cooperation Treaty (PCT) procedure<sup>21</sup>, a unified worldwide patent application system administered nationally by the Canadian Intellectual Property Office (CIPO) – a growth rate of 88% from 1999 to 2013 (OECD, 2016b).

The technological strength and quality of a country's patented innovations are commonly indicated by *triadic patent families*<sup>22</sup> (OECD, 2009). Compared with key competitors, Canada generates fewer triadic patents per unit of industry-financed R&D in all economy sectors.

In the agriculture sector, the number of triadic patents filed by Canadian inventors has dropped progressively from the 1999-2012 period, filing an average of six triadic patents annually (OECD, 2016b).

The private sector has been the main contributor of patents in the agriculture sector in recent years (1997-2012) accounting for a share of 58%, followed

by post-secondary institutions (26%) and federal agencies (12%) – mainly comprised of AAFC, NRC and Natural Resources Canada (Science-Metrix, 2015).

#### **Plant Breeders' Rights**

Plant breeders' rights (PBRs) are another form of IPR by which plant breeders can protect new varieties, allowing owners to prohibit specific unauthorized uses. PBRs provide plant breeders with stronger protection and a greater return on investment, as well as allow for better access to varieties coming from other countries having a positive impact on the availability of improved varieties for producers.

Since Canada's plant breeders' rights laws were updated in 2015 to bring them in line with the International Union for the Protection of New Varieties of Plants (UPOV) 1991, there has been a 25% increase in new applications and 5000 different varieties protected under the Plant Breeders' Rights Act (PBRA) over the 1999-2012 period (Roch, 2016).

### B.3.3. Knowledge Transfer, Extension and Advisory Services

Traditional knowledge diffusion pathways such as the publication of research, academic conferences and the commercialization of intellectual assets remain a necessary condition and first step for disseminating agricultural research results. Nevertheless, additional dissemination channels are needed to ensure research results get into the hands of key stakeholders and incorporated into agricultural practices on the ground.

#### **Extension and advisory services**

Despite major organizational and operational changes in the delivery of advisory and knowledge transfer services during the last twenty years (OECD, 2015), public programs continue to play a role in Canadian agricultural extension.

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<sup>20</sup> Patents filed by inventors residing in Canada.

<sup>21</sup> Applicants file a single international application (PCT application) with the Canadian Intellectual Property Office (CIPO) and then, begin the application process in other countries. The PCT procedure is currently the preferred patenting route among inventors targeting worldwide markets.

<sup>22</sup> The number of patent applications filed at the European Patent Office (EPO) and the Japan Patent Office (JPO), and granted by the US Patent Trademark Office (USPTO).

Industry associations and commodity groups have increasingly taken the leading role in extension activities with the use of new electronic and online information sharing channels to provide data to farmers and producers, as well as coordinating continuing education, workshops and e-learning opportunities to facilitate stakeholders' understanding of technical knowledge.

While farmers and producers can benefit from new digital technologies, information and technical resources, the lack of a common analytics platform and rural broadband (ACEG, 2017) often prevents research end-users from realizing the full potential of dissemination initiatives carried out by other actors across the sector.

The private sector is also increasingly active, offering extension and consulting services that vary in accordance to regional particularities – about half of Québec's agrologists, for example, work in private extension (OECD, 2015) while in some other provinces, like Saskatchewan, there is still a strong government lead in the delivery of extension services.

### ***Trends in farm-level adoption***

Although the delivery of extension services has changed dramatically over the last decades, at least one type of agricultural innovation was adopted on about half of Canadian farms (48%) between 2011 and 2013 (AAFC, 2016).

Farm size and revenue have a substantial impact on the adoption of new knowledge and technologies. Larger farms (over \$1-million annual revenue) are the most likely to implement agricultural innovations and seek advice from public or private extension specialists than smaller farms (AAFC, 2016).

Farmers' openness to innovation is also an important determinant. Producers increasingly rely on their own experience and experimentation rather than third-party advice to implement a new technology or process.

The vast majority of farmers in Canada tend to adopt innovations only after they have been influenced by and made aware of others' experiences, while the rest will most likely wait until new products, processes and practices are fully tested and vetted (AAFC, 2016).

Particular commodity sectors are also more open to adopting agricultural innovation than others. Horticultural and potato farmers, for example, are more likely to be early adopters than beef cattle or dairy (AAFC, 2016).

With more than half of farms using computers, laptops, smartphones and tablets to support their day-to-day operations, Canadian producers are increasingly introducing digital technologies into their farm management practices (Statistics Canada, 2017g) (Image B.8).

A shift towards precision agriculture has also encouraged the adoption of innovative decision-support tools, ranging from Global Positioning Systems (GPS) to Geographic Information Systems (GIS), enabling farmers to increase productivity while achieving better efficiencies (Statistics Canada, 2017g).

Increased efficiency in the dairy industry, for example, has been achieved, among other factors, through improvements in genetics and advancements in technology, including the use of robotic milking which accounts for 8.9% of dairy type operations (Statistics Canada, 2017h).

The adoption of other farm-level innovations – plant genetics, fertilizer, no-till seeding technology and changes to the mix of crops cultivated – has also acted to reduce summerfallow acreage by 57.1% since 2011, thus contributing to the attainment of environmental sustainability goals in the sector (Statistics Canada, 2017e).

### ***Technology acquisition in the food processing sub-sector***

Overall, food processing companies are less innovative than other types of manufacturing enterprises, ranking 17 out of 21 manufacturing sub-industries in the adoption of innovations between 2012 and 2013 (Statistics Canada, 2014).

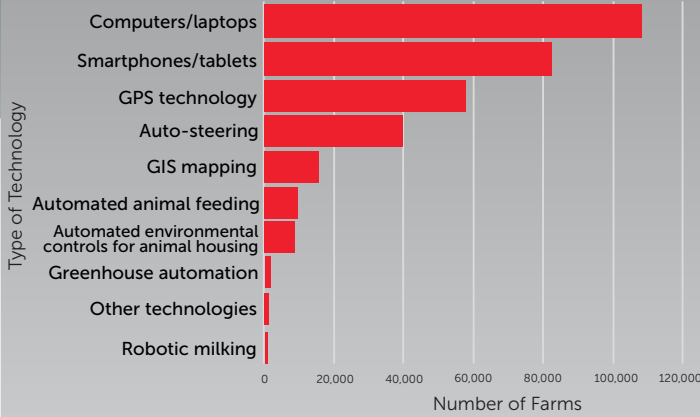
According to the latest *Survey of Advanced Technology*, over half (56.9%) of the food processing enterprises surveyed acquired off-the-shelf advanced technologies to integrate innovation into their production processes. The next most common means of adopting technological innovations were customizing existing advanced technology (16.1%) and licensing (14.5%) (Statistics Canada, 2014b).

With only 1.4% of surveyed companies partnering with academic or research organizations, this is one of the least popular mechanisms of adoption. Rather than collaborate with post-secondary institutions, food processing business (4.5%) prefer to team up with other private sector companies to acquire new technologies (Statistics Canada, 2014b).

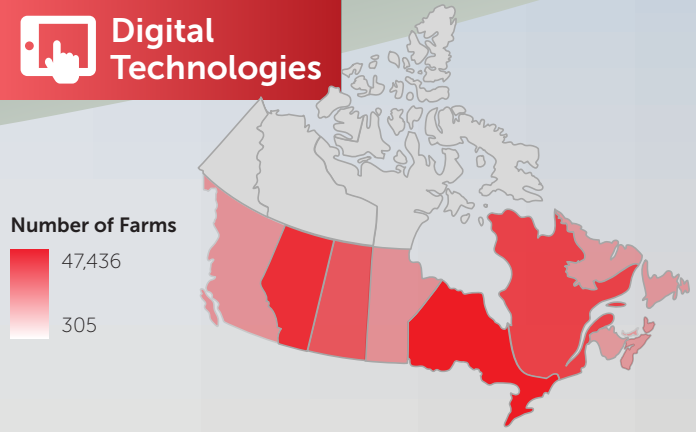
Within the food processing sub-sector, grain and oilseed milling reported the highest percentage of companies introducing innovations (78.4%), followed by sugar (74.6%) and meat product manufacturing (71.4%) (Statistics Canada, 2014).

## Adoption of On-Farm Technologies

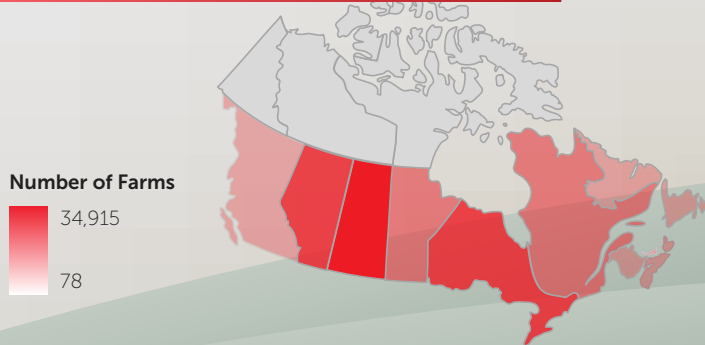
### Farms Reporting Use of On-Farm Technologies Canada-wide data, 2016



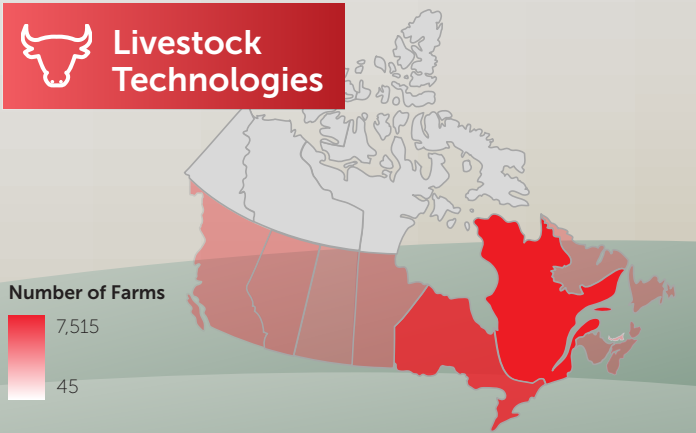
### Digital Technologies



### Technologies Applied to Precision Agriculture



### Livestock Technologies



<sup>1</sup> Automated animal feeding, automated housing controls and robotic milking.

Source: Statistics Canada. Table 004-0243 - Census of Agriculture, farms reporting technologies used on the operation in the year prior to the census, every 5 years (number)

Image B.8. Adoption of On-Farm Technologies

# C. Analysis: Challenges and Opportunities for the Canadian Agricultural Innovation System

A rapidly-growing world population, rising income in developing countries and favourable global market trends are expected to raise demand for agricultural products worldwide, leading to an estimated annual growth of 1 to 2% in Canada's agriculture trade between 2016 and 2025 (AAFC, 2017).

Our agriculture sector was also identified by the federal government's Advisory Council on Economic Growth (ACEG) as one of the most promising in terms of economic development, employment and innovation capacity. The *Barton Report* (ACEG, 2017) highlights the potential contribution of agri-food production to Canada's economic growth, setting a target to grow agricultural exports from \$55 billion in 2015 to at least \$75 billion by 2025.

Productivity gains arising from the development of new technologies and knowledge thus play a fundamental role in increasing the supply needed to meet the world market's growing demand. Agricultural innovation can contribute to maintaining Canada's competitive position internationally while optimizing labour, natural resources and infrastructure thereby reducing

commodity prices to benefit producers, consumers and all actors along the length of the agriculture and agri-food value chain.

A strong scientific base, a broad network of stakeholders, and multiple innovation hubs provide Canada's agricultural sector with valuable tools to untap the sector's full potential at a global scale (ACEG, 2017). Nevertheless, current productivity gains will be unable to sustain momentum in the changing global trade environment as increases in land use are no longer available, rising commodity price volatility threatens profits, and advances in agriculture technology are progressively slowing (FCC, 2016).

Canadian producers will also be challenged to maintain or expand market share with other economies in the face of growing competition (AAFC, 2017) from emerging agricultural export countries capitalizing on sector reforms that include the development and adoption of new technology such as advances in data analytics, automation, and genomics among others (ACEG, 2017).

## The Dutch Agricultural Innovation System

With a long tradition of trade, a strategic geographic advantage and natural resource wealth, the Netherlands, at first glance, seems to be primed to become a prominent agri-food trader. A closer look, however, reveals several factors that have combined, further strengthened the Netherlands' 'natural' competitive advantage, particularly an increased emphasis on innovation policies aimed at raising agricultural productivity (ACEG, 2017).

Despite a modest increase in the volume of its scientific production in agriculture, with a percentage growth of 43% compared to Canada's 40% between 1997 and 2014, the Netherlands ranks first place in scientific impact of agricultural research worldwide (Science Metrix, 2015).

### How was this achieved?

The Dutch government has worked closely with agri-businesses on a range of initiatives to ensure a high level of private-sector investment in agriculture R&D (BERD) (ACEG, 2017), to develop intensive production facilities such as greenhouses, and to invest in human capital by educating a highly-skilled agricultural workforce (FFC, 2016).

The establishment of strong innovation hubs that draw on expertise from across sectors in businesses, academia and government agencies has also played a key role in the growth of the Dutch agriculture sector. *FoodValley*, for instance, geographically concentrates international food companies, research institutes and the Wageningen University and Research Centre to boost competitiveness and technological development.

## C.1. Return on Investment and Balanced Funding Models for Agricultural Research

There are two leading methods to measure the impact of investments in agricultural research on the ground. The first, traditional supply-demand models show that scientific and technological developments raise production, increasing the quantity of agri-food products consumed and lowering prices.

The second, return-on-investment (ROI) studies, repeatedly indicate very high rates of return on agriculture R&D investments worldwide regardless of the type of research (basic or applied), the area of research, or who performed the research (public or private sector) (Table C.1).

Internal rate of return per year for agriculture R&D	
Applied Research	139.5%
Basic Research	42.9%
Extension	72.2%

Table C.1. Worldwide estimates for internal rate of return for agricultural R&D (Hurley, Pardey, Rao & Andrade, 2016)

Note: Internal Rate of Return is the interest rate that equates the present value of an investment's benefits to the present value of its costs (Hurley, Rao & Andrade, 2016). The IRR (the annual growth rate) exceeds and diverges from the total rate of return (ROI) as research investments become more profitable in the long-term.

High Canadian and global benefit-cost ratios for agricultural research – estimated to range from 10:1 to 20:1 (Alston, Gray & Bolek, 2012) – confirm that the annual value of agricultural productivity gains attributed to agriculture R&D is worth many times more than the annual value of expenditures on research.

Very large marginal benefit-cost ratios may, however, reflect substantial and continued underinvestment in agriculture R&D in individual countries and the world as a whole, suggesting that it would likely have been profitable to have invested much more in this area (Alston, 2010).

Despite this evidence, public spending on agriculture R&D has gradually decreased not only in Canada, but in many other developed countries over the last decades (Hurley, Pardey, Rao & Andrade, 2016).

This has an enormous impact on the Canadian AIS where the public sector continues to be the largest source of funding for agriculture R&D whether performed in the public or private setting.

Significant risks arise from a strong reliance on public funding, including a gradual reduction of Canada's capacity to innovate and the creation of economic disincentives and uncertainty for other actors to invest in agricultural research. The private sector, for example has not been incentivized to invest in agricultural research to the same level as they have in other industries (OECD, 2015).

Other key funders of agricultural research, such as the private sector, also appear to either under-invest or decrease their expenditures in R&D due to low short-term returns on investment. However, despite the significant time gap between initial investment and in-field application of innovations, agriculture R&D has proven to have a positive, long-lasting impact on productivity growth (Alston, 2010).

World-leading Canadian performance in canola production – the country's second-largest crop by volume – reflects the delayed impact of innovation on the economy. Through cross-sectoral collaboration, in the early 1970s, Canadian scientists developed a variety that could serve new markets, but it was not until 2015 that Canada's exports of canola rose by almost 200 percent (ACEG, 2017).

### ***Innovation and productivity growth***

Increases in production arising from using a given combination of existing labour, capital inputs and resources allow producers to achieve particular, often commodity-specific project targets.

However, if the sector as a whole is to meet future global demand for agricultural commodities without stressing our natural resources, Canada must generate higher productivity growth – an increase in overall production levels through investment in key assets that can raise real income over time (FCC, 2016).



Total Factor Productivity (TFP) growth – or Multifactor Productivity growth – compares the total amount of crop and livestock output to the total inputs – land, labour, capital, and natural resources – used to generate that output. TFP increases when total output rises faster than the total inputs used – indicating high intensity utilization of inputs (FCC,2016).

Historically, TFP growth has been the driving force for Canada’s agricultural production (OECD, 2016). Nevertheless, after a significant upward TFP trend registered between 1970 and 1980 following the introduction of major agricultural technological advances, productivity gains have not maintained a stable path over the last decades (FCC,2016).

Canada’s current annual TFP growth appears to be relatively stagnant and stationary at 1.6% after a marked decline in 1990. Furthermore, Canada’s agricultural productivity growth is reportedly lower than that for most OECD countries (FCC, 2016).

With a relatively larger percentage of larger farms, the average size of Canadian farms (Statistics Canada, 2017e) increases the opportunities for many commodity sectors to achieve the economies of scale needed to draw on technological innovations to enhance productivity.

Government support to producers has, however, been mostly geared towards smoothing volatility and managing risk at the farm level rather than investing in variables affecting productivity growth such as the adoption of new technologies – even when a greater proportion of budgetary transfers has been gradually shifted to finance the agricultural knowledge and innovation system (OECD, 2015).

### ***Proprietary Rights as Incentives to Innovate***

Along with determining the direction of funding, governments can also encourage innovation through policy incentives, particularly the establishment and enforcement of property rights. This exclusive right conferred on inventors that temporarily turns an innovation from a public good into a private good, brings a significant incentive for scientists and firms to engage in research. A lack of strong intellectual property rights (IPR) in the sector however, has contributed to further reduce incentives for agri-businesses to invest in agricultural research.

Evidence shows that certain types of agricultural R&D – crop breeding for example – have benefited from increased private and total investment due to characteristically strong IPR and potential for considerable research gains (Alston, Gray & Bolek, 2012). Approximately 95% of private sector crop breeding research in Canada is targeted towards only three crops – canola, corn and soybeans - crops that characteristically have stronger forms of intellectual property protection (OECD, 2015).

An increased emphasis on private R&D and overly enforced IPR can however hamper cross-sectoral research in the sector – collaboration that is crucial to efficient knowledge transfer and broad dissemination of information.

### ***Spurring Innovation in Canadian agri-businesses***

Business-led innovation is essential to extract value from science and technology. An attractive climate for private investment in agriculture, coupled with targeted incentives, can increase the potential of innovative companies willing to capitalize on our research capacity, stimulating Canada’s competitiveness and enhancing job growth.

Nevertheless, Canada’s performance in this area has increasingly declined against that of key competitor countries such as Australia and United States.

Although tax incentives for firms to invest in R&D for all industrial sectors are widely available, special tax provisions for agri-businesses, farmers and producers could help better promote technology development, transfer and adoption in the sector.

Agri-entrepreneurs too play a major role in supporting the development and deployment of innovations at the farm level. With targeted incentives, agricultural small and medium enterprises (SMEs) producing at a scale that requires capital and support services to grow could foster innovation as a key strategy for achieving greater returns.

While opening up promising opportunities for commodity groups and post-secondary institutions, strategic business alliances can also help Canadian R&D achieve a competitive advantage at the international level, enabling the environment needed to maximize knowledge transfer strategies in collaborative research projects.

New emerging areas of research in the value-added agriculture and agri-food processing sector, similarly to biotechnology, offer new and attractive opportunities for science graduates, researchers, and agri-entrepreneurs. The increasing growth experienced in this area demands both financial and non-financial incentives to conduct and disseminate innovative research that anticipates the production needs of current and future markets.

### ***Moving Forward: Investment Strategies for Agricultural Innovation***

Matching investment strategies encouraging partnerships that leverage private and industry investments leading to applied research projects geared toward commercialization still have a decisive role to play in the in the development of Canada's agricultural sector.

Agricultural policy frameworks have continued to recognize the importance of collaborative research particularly after the early successes of the 1995 *Agri-Food R&D Matching Investment Initiative* (MII) which produced over nine hundred applied-research projects in a five-year period (Doern, Phillips & Castle, 2016).

Investment intentions or research priority setting however should not be only driven towards downstream knowledge with potential to be used in development and production. Scientific research that advances the state of knowledge – basic research – is a valuable public good and the foundation of agricultural innovation, and must continue to receive adequate support.

In this context, a combination of funding mechanisms – public, levy-based and private funding – can be tailored to suit the particular needs and characteristics of the Canadian AIS, ensuring all types of research are adequately supported.

With strengthened cross-sectoral collaboration, the development and expansion of strategic research clusters – or *superclusters* – can also contribute to creating new opportunities to leverage R&D investments and driving efficiencies.

## C.2. Scientific Base Capacity and Deployment

Increasing specialization in science and technology has made Canada's strong scientific base and highly educated population – ranking 12<sup>th</sup> out of 34 countries in doctorate holders per 100,000 people (OECD, 2015b) – a cornerstone of the modern innovation system.

Nevertheless, over the last ten years, Canada has been experiencing substantial labour shortages in agriculture, including commodity-specific research specialists and technicians, with a labour gap expected to drastically grow by 2025 (CAHRC, 2016b).

Primary agriculture reports a high job vacancy rate (9%) relative to other sectors of Canada's economy (CAHRC, 2009) and some provinces have reported significant growth in the demand for highly-skilled workers in the agriculture sector (OECD, 2015). An analysis of the food processing industry as well has indicated that firms face obstacles to innovation due to skilled labour shortages (AAFC, 2015).

Graduates from agri-food and agriculture programs at the University of Manitoba receive an average of 1.85 job offers by graduation (CFAVM, 2013). Meanwhile in Ontario, agri-food employers' demand far exceeds the supply of post-secondary graduates in agri-food programs, with three jobs offers for every agriculture graduate with a bachelor's degree (OAC, 2012).

Although agricultural post-secondary programs have been experiencing high to, in some cases, near-capacity enrollment (CFAVM, 2013), studies have noted that the agriculture sector has not effectively marketed itself to youth in order to attract enough students to meet the demand for skilled labour (CAHRC, 2009).

Guidance and career counselling information for high school students interested in pursuing careers in research, as well as investments in education through grants, scholarships and infrastructure can potentially help address these human resource challenges.

Skilled labour shortages, in particular, have a substantial adverse impact on the innovation continuum, particularly on the dissemination of agricultural research. Almost all farmers (91%) report that they rely on their own knowledge, experience and experimentation in their decision to implement innovation (AAFC, 2016). Extension specialists and highly educated producers capable of understanding and transferring agricultural innovation are therefore needed to ensure that research is adopted promptly on the ground.

Participatory research approaches bring valuable opportunities to engage science graduates in research projects, extension services and knowledge transfer activities that give them the opportunity to work alongside producers. It also helps ensure research responds more effectively to end-users' needs and that technologies can be adopted more widely on Canadian farms.

The private sector too has an important role to play, bringing increased opportunities to attract highly skilled personnel through internships and co-op programs that give post-secondary students valuable hands-on experience in business-led R&D.

The hiring and retention of a skilled labour force, however, demands the development of human resource plans aligned with strategic business planning. Business management training courses or programs focused on solutions to the human resource challenges in the agriculture sector are thus a significant priority (CAHRC, 2009).

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## Provincial Data Sources

### Image B.4. Funding Trends in Agriculture R&D

#### Alberta

Expenditures in Livestock Development (Alberta Livestock and Meat Agency Ltd.), Agriculture and Food Innovation Endowment Account and Industry Development (Department of Agriculture and Forestry). *Source:* Financial Statements of the Alberta Livestock and Meat Agency Ltd., and Alberta's Department of Agriculture and Forestry (2010 -2016).

Note: Figures from 2010 to 2013 include Food Safety and Inspection expenditures.

#### British Columbia

Expenditures in Innovation and Adaptation Services (Innovation and Governance for 2013 and 2012), and Plant and Animal Health. *Source:* Public Accounts, Province of British Columbia (2010 - 2016).

Note: Figures for 2010 and 2011 include Food Safety and Inspection expenditures.

#### Manitoba

Expenditures in: Research and Market Intelligence, Grain Innovation Hub, Manitoba Biomass Energy Support Program, Farmland School Tax Rebate, Livestock Industry, Crop Industry, Agri-Resource, Growing Opportunities Centres, Food Development Centre, Food and Agri-Product Processing (2016), Agri-Innovation and Adaptation, Agricultural Sustainability Initiative, Manitoba Biomass Energy Support Program, Farmland School Tax Rebate, Livestock Industry, Crop Industry, Agri-Environment, Growing Opportunities Centres, Food Development Centre, Food Commercialization and Marketing (2015). Agri-Innovation and Adaptation, Agricultural Sustainability Initiative, Farmland School Tax Rebate, Livestock Industry, Crop Industry, Agri-Environment, Growing Opportunities Centres, Food Development Centre, Food Commercialization and Marketing (2014 and 2013). *Source:* Annual Reports, Manitoba Agriculture, Food and Rural Development (2013 - 2016).

#### New Brunswick

Expenditures in Innovation and Market Development and Sector Specialist Services (for 2016 and 2015), Biosciences and Agriculture Specialist Services (2014), Crop and Livestock Development (2013, 2012, 2011 and 2010). *Source:* Public Accounts of the Province of New Brunswick, Department of Agriculture and Aquaculture (2010 - 2016).

#### Newfoundland and Labrador

Expenditures in Research and Development, Animal Health, and Production and Market Development (2010-2016). *Source:* Annual Report, Department of Forestry and Agrifoods (2010-2016)

#### Nova Scotia

Expenditures in Agriculture and Food Operations (AR), grants to Dalhousie University and Perennia Food and Agriculture (PA) for 2016, 2015 and 2014; Agriculture and Food Operations and N.S. Agricultural College(AR), grants to Dalhousie University and Perennia Food and Agriculture (PA) for 2013; Agriculture and Food. *Source:* Public Accounts (PA) of the Province of Nova Scotia (Vol. 3) and Annual Report (AR), Department of Agriculture (2011 - 2016).

#### Ontario

Expenditures in Research Program and Capital Expenses in Research and Education Infrastructure. *Source:* Public Accounts of the Province of Ontario, Ministry of Agriculture, Food and Rural Affairs (2010 - 2016).

#### Prince Edward Island

Expenditures in Agricultural Innovation, Sustainable Agriculture Resources, and P.E.I. Analytical Laboratories. *Source:* Public Accounts, Province of Prince Edward Island (2010 - 2016).

#### Québec

Expenditures in Institut de technologie agroalimentaire expenditures, and transfer expenses to: Assistance for Research and Technology Transfer, Regional Development Assistance, and Support for Training. Regional Development Assistance consists of extension and commercialization programs. *Source:* Public Accounts of the Province of Québec, Ministère de l'Agriculture, Pêcheries et Alimentation (2010 - 2016).

#### Saskatchewan

Expenditures in Agricultural R&D and demonstration of new practices and technologies at the farm level. Data directly provided by the Agriculture Research Branch, Ministry of Agriculture, Government of Saskatchewan.

# Key Terms\*

Agriculture and Agri-Food System	Value chain of industries focused on producing agricultural and food products. It includes agricultural input and service suppliers, primary agriculture, food, beverage and tobacco processors, food retailers/wholesalers, and foodservice establishments.
Agricultural Extension	Services and activities that include an educational component aimed at sharing research outputs and know-how knowledge in agronomic techniques with farmers to improve their production, income and quality of life, allowing them to capture a greater share of the value chain.
Agricultural Innovation	Agricultural innovation encompasses science and technology (S&T), research and development (R&D) and the adoption of scientific research outputs such as new production techniques or improved farming practices (OECD).
Agricultural Research	Any research activity focused on any of the following subfields: agricultural science (agronomy, agricultural engineering, irrigation, weed and pest control, agroforestry, agricultural economics and policy, plant sciences, and land resource and soil science), veterinary sciences (animal welfare), food sciences (cereals, dietetics, etc.), renewable bioresources (mostly biofuels) and aquaculture.
Agricultural Research and Innovation Stakeholders	Farmers, ranchers and producers, federal and provincial governments (the public sector), agri-businesses and agri-entrepreneurs (the private sector), industry and professional groups, post-secondary education institutions (universities, colleges, CEGEPs and polytechnics), non-profits and international partners, extension providers and professional agrologists, the Canadian public and consumers.
Agriculture Sector	Sector of the economy composed of all industries whose primary role is to produce food and agricultural products. It encompasses both primary agriculture and food, beverage and tobacco processors.
Applied Research	Original investigation undertaken in order to acquire new knowledge directed primarily towards a specific practical aim or objective.
Basic Research	Experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view. Basic research is also called pure or fundamental research.
Cross-sectoral research	Research conducted in conjunction with the public and private sectors, academia and/or producer associations. Contribution of funding and/or resources (personnel and research infrastructure) from both public and private sources.
Dissemination	Active process to communicate research results to potential end-users by using targeted strategies and products to increase the likelihood of adoption.
Environmental Sustainability	Use of existing natural resources while maintaining its potential future benefit.
Food processing (sub-sector)	Agricultural sub-sector that consists of establishments that transform raw agricultural commodities and semi-processed food products into a broad range of food and beverage products ready for consumption or for further processing.
Highly Qualified Personnel (HQP)	Individuals with university degrees at the bachelors' level and above.
Innovation	Implementation of a new or improved product, marketing method, or organizational method in business practices, workplace organization or external relations.

\* The following definitions have been compiled from both national (AAFC, ISED, Statistics Canada) and international (FAO, OECD, UNESCO) sources and supplement those already included in the the report.




# Key Terms

Innovation Systems	Conceptual framework used to understand the process of innovation in agriculture – from S&T and R&D to knowledge transfer and extension – that emphasizes how the interaction and relationships between multiple actors determines the overall performance, impact and scope of innovation processes.
Intellectual Property Rights	Assignment of property rights through patents, copyrights and trademarks. These property rights allow the holder to exercise a monopoly on the use of the item for a specified period.
Interdisciplinary research	Type of collaborative research that combines expertise from two or more disciplines to solve complex issues whose solutions are beyond the scope of a single discipline or area of research.
Knowledge Transfer	Process of transferring research outputs from knowledge producers to knowledge end-users.
Primary Agriculture	Agricultural sub-sector composed of crop and animal production, as defined by the North American Industrial Classification System (NAICS).
Public-Private Partnership	Research conducted in conjunction with both the public and private sector. Contribution of funding and/or resources (personnel and research infrastructure) from both public and private sources.
Research	Any creative systematic activity undertaken in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this knowledge to devise new applications.
Research and Development (R&D)	Term covering three activities: basic research, applied research, and experimental development. R&D activities comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge and the use of this stock of knowledge to devise new applications.
Research End-Users	Farm community groups, farmers, farm associations and producers, funders and potential future partners, rural communities, research communities, consumers and linking agents.
Science and Technology (S&T)	Activities as encompassing the traditional disciplines in the natural sciences—the study of nature; the social sciences, humanities and health sciences—the study of human beings; and engineering—the creation and study of artifacts and systems.
Technical Support Staff	Research personnel whose main tasks require technical knowledge and experience in one or more fields of engineering, physical and life sciences, or social sciences and humanities. They participate in research and development (R&D) by performing scientific and technical tasks involving the application of concepts and operational methods, normally under the supervision of researchers.
Technology	Refers to the state of knowledge concerning ways of converting resources into outputs. Technology is broadly defined to include the technical means and know-how required to produce a product or service. It takes the form of equipment, materials, processes, blueprints and knowledge.
Technological Innovations	New products and processes and significant technological changes of products and processes. An innovation has been implemented if it has been introduced on the market (product innovation).
Technological Progress	Technological change that leads to increases in output for any given input, including capital, natural resources and labour.
Technology Transfer	Process of transforming technology innovations into products for wider use.
Value-Added Production	Value-added production refers to products that have undergone some processing.



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