School of Public Policy

UNIVERSITY OF CALGARY

BRIEFING PAPER
Volume 17:01
January 2024

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Sustainable Innovation in the Canadian Agrifood Sector: Past, Present & Future

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Acknowledgements

This work was supported by UFA Co-operative Ltd. and the Rural Communities Foundation (RCF) in a sponsorship agreement that supports research, research dissemination, and public outreach. The sponsors were not involved in the study design, collection, analysis, interpretation of data, the writing of this article, or the decision to submit it for publication.

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EXECUTIVE SUMMARY

In order to remain globally competitive with sustainable innovations in agri-food, both the public and private sectors in Canada must increase investment and in the industry.

Studies reveal that both sectors' support for agri-food innovation has declined in recent years. To spur innovation and growth public funding should revert to previous levels, ideally reaching 0.10 per cent of GDP. Incentives such as tax relief, matching funds and enhanced protection of intellectual property rights could spur increased levels of private sector investment in innovation.

In the past 50 years, innovation in agriculture has brought tremendous benefits to producers, processors and consumers. Successful innovations include genetically modified crops, large-scale cattle feeding operations and the adoption of no-till farming, which has reduced the traditional practice of summerfallowing fields. Still, with the demand for a secure global food supply and growing concerns about the environmental impacts of large-scale farming, the need for sustainable innovation in the agri-food sector is pressing.

This paper offers three recommendations for policy-makers. First, public funding for agricultural research and development should be increased to prior levels. Next, the private sector needs more favourable conditions to foster investment in the agri-food industry. Last, if intellectual property rights are strengthened, innovating firms will be reassured that they can capture the economic benefits innovation creates.

Recent reports by the Agriculture Institute of Canada and the Organization for Economic Cooperation and Development have found that Canada's support for agricultural innovation ranks seventh globally at 0.046 per cent of GDP, but that figure is still considerably below historical averages. Private-sector investment has also declined, with Canada ranking 25th globally in 2014, down from 18th place in 2008.

Research and development requires more sources for venture capital, while smaller firms would stand to benefit from tax incentives just as their larger counterparts do. Digital infrastructure must be upgraded so that rural broadband service is expanded and reliable, as the uptake of new digital technologies by farmers is critical to the agri-food sector's success. Regulations should be simplified and updated, the addition of skilled labour to the agri-food workforce facilitated and more use must be made of information technology.

Canada's record in agri-food innovation speaks for itself. Thanks to genetic modification, crop damage has been reduced with a corresponding increase in pest control. Yields are up by 21 per cent, cost savings on pesticide use have risen to 39 per cent and the resultant profitability for farmers who grow GM crops has gone up 69 per cent. With global crop demand predicted to double by 2050, innovation can provide huge benefits for all stakeholders in the agri-food industry, and more food can be grown to feed the world's expanding population.

As a world-leader in building a sustainable, profitable and safe agri-food system, Canada can be a pre-eminent hub for innovation. However, senior levels of government must commit to developing Canada's potential and to creating an environment that encourages private investment.

Canadian scientists are working tirelessly to develop developing new and improved crops and animal genetics and showcasing their work through scientific publications and presentations. Canada can be immensely proud of its innovation record in agriculture, and by implementing the recommendations outlined in this paper, this country can continue to count itself among world leaders in this regard.

INTRODUCTION

Despite frequent claims to the contrary by less reputable occupations, farming is the world's oldest profession. Throughout agricultural history, which is virtually as long as human history itself, those engaged in agricultural activities have striven to innovate — to improve through both conventional methods and genetic modification the variety, viability and vigour of crops and animals available for human use. The earliest innovations in agriculture mainly involved agronomic practices, whereby early humans progressed from gathering berries, seeds and nuts to deliberately cultivating them, while the newest innovations see humans modifying the DNA of plants and animals in order to tailor them to specific uses. Agricultural innovation in the production and processing of food has allowed humans to increase farm productivity, have the safest and most plentiful food supply of any time in history and enhance the incomes and food security of the world's poorest farmers (Alston and Pardey 2021).

Given the growing world population's need for a secure food supply, coupled with societal concerns regarding the environmental impacts of large-scale agricultural production, the necessity of sustainable innovation in the agri-food sector has never been more pressing. In exploring the concept of sustainable agriculture in Canada more than 30 years ago, Gray (1991) defined it as "… the maintenance of the net benefits agriculture provides to society for present and future generations." In that work, he explicitly acknowledged agriculture's environmental impacts and explored the dual (sometimes competing) objectives of ensuring an abundant food supply while also recognizing food production as an economic activity that at least in part has the goal of providing income for farmers and others.

The objective of this paper is thus to explore the interlinkages between innovation and sustainability in the Canadian agricultural sector, with a historical focus upon the most impactful innovations in the last half-century as well as an analysis of the current set of policy and incentive mechanisms targeted to fostering innovation. In this context, a set of recommendations pertaining to sustainable agricultural innovation policy in Canada will be made. Relatively recent work by the Agricultural Institute of Canada (AIC 2017) and the Organization for Economic Cooperation and Development (OECD 2015) has provided significant background and details on agricultural innovation in Canada. Given these recent efforts, the intent here is not to duplicate what is already known, but rather to provide an overview of specific innovations with a focus on Western Canadian agriculture and identify potential strategies for innovation policy in Canada in the coming years.

AGRICULTURAL INNOVATION: THE CANADIAN CONTEXT

When "innovation" is broadly interpreted, it is no exaggeration to suggest there have been hundreds of thousands of innovations in the history of agriculture. For example, there are more than 30,000 varieties of wheat alone (Kansas Farm Bureau 2023), and with many dozens of other crops — not to mention animals, agronomic practices and technological innovations — the array of agricultural innovations occurring historically is breathtakingly vast. The Canadian agricultural landscape has benefited enormously from innovations in several different categories — none more important than in new varietal development for crops and improvements in both agronomic practices and soil management. Figure 1 shows average yields for three major Canadian field crops (wheat, canola/rapeseed (introduced in 1943) and barley; other significant crops such as corn are not shown but demonstrate the same general trend) from 1908 through 2023. As Figure 1 shows, after a period of somewhat stagnant yields through 1950, steady innovation

has more than doubled average yields for these crops in the last half-century or so. Figure 2 shows total production of these three important crops in Canada, highlighting how innovation has dramatically increased the supply of food being grown in Canada for the benefit of Canadians as well as global consumers.

Figure 1. Average Yields (bu/acre) for Wheat, Canola and Barley in Canada, 1908–2023

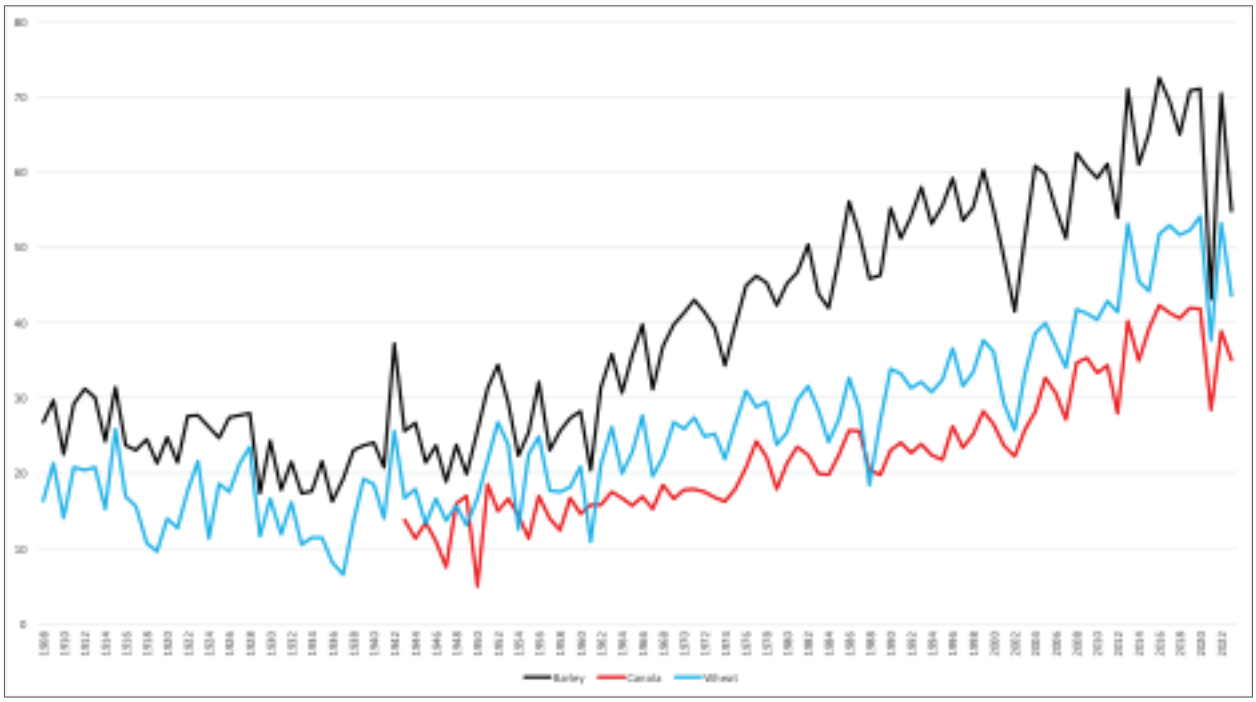
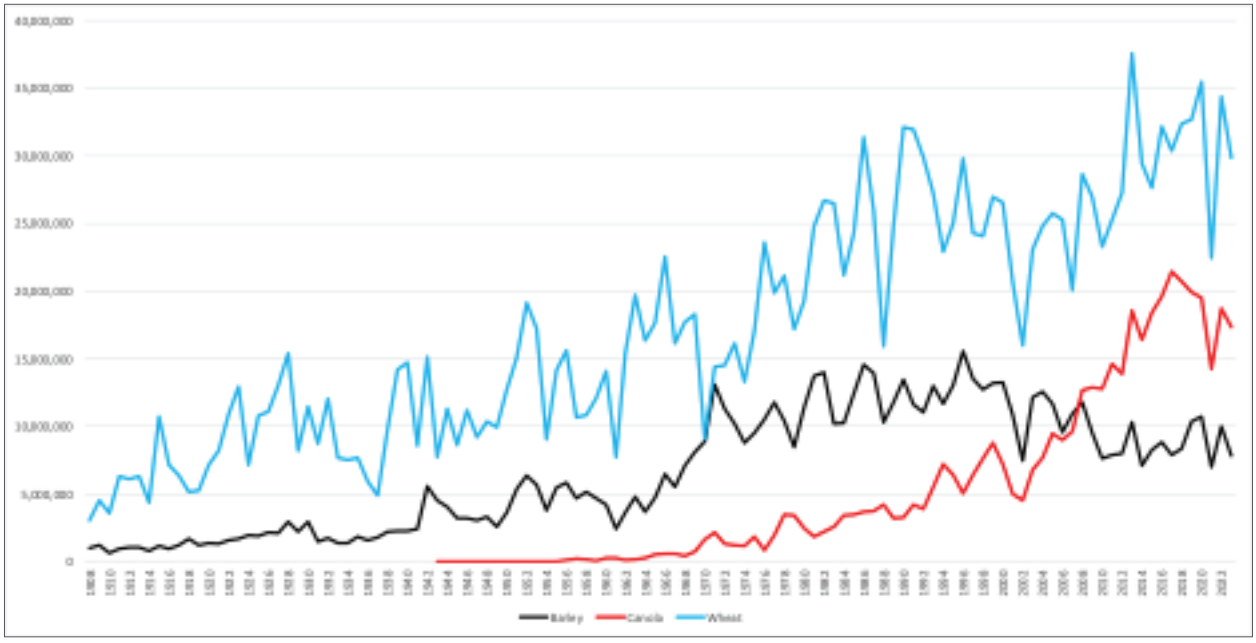


Figure 2. Total Production (metric tonnes) of Wheat, Canola and Barley in Canada, 1908–2023



Source: Statistics Canada (2023a) and author's calculations

Previous examinations of the Canadian agricultural innovation system have recognized the importance of improvements to technologies and farming practices given Canada's prominence as a significant exporter of food to the world. As noted above, both the AIC (2017) and the OECD (2015) have recently undertaken significant (184 pages and 42 pages, respectively) explorations of the agricultural innovation system in Canada. Alston et al. (2012) conducted a similarly thorough (80 pages) investigation of agricultural research investments in North America that ostensibly focused on farmer-funded R&D, but also carefully considered the broader innovation environment. Accordingly, its observations and conclusions are appropriate to consider when providing an overview of the current climate for agricultural innovation in Canada.

The AIC (2017) report provides a detailed overview of various aspects of federal funding levels and programs. The report discusses the roles of the federal government, public/private partnerships (P3s, and even P4s which include producers as partners) and the strong presence of agriculture in the federal government's Science, Technology and Innovation Strategy. The strategy's focus of particular interest to agriculture is water security, climate change research, food systems and food, aquaculture and, of course, biotechnology. Main strategic objectives include enhancement of agricultural productivity, improving the attributes of crops and animals for both food and non-food purposes and improving performance from an environmental perspective.

Common threads emerge from the OECD (2015) and AIC (2017) reviews. Perhaps the most important is that, just like across much of the world, public support for agricultural innovation systems has generally been in decline, despite strong evidence that returns on investment in this area are substantial. The AIC (2017) report notes that while public expenditures in this area have been declining in Canada, they still rank seventh globally at 0.046 per cent of GDP, although this is well below historical averages in this country. Those authors also note that public spending on agriculture R&D in Canada outpaces private investment by a factor of about nine to one, suggesting that efforts to spur additional private-sector support are warranted. They further observe that crop and livestock producers in Canada adopt new innovations at about the same rates and that larger farming operations are somewhat more likely to adopt a new technology or farming practice than their smaller counterparts. The OECD (2015) report also laments the general decline in funding for agricultural R&D, but observes that the macroeconomic and policy conditions in Canada are generally conducive to the levels and types of investments required to spur productivity growth, a main issue identified by Alston et al. (2012).

A second common thread from previous analyses of agriculture innovation in Canada is the importance of incentivizing greater levels of private investment. The AIC (2017) report observes that in both absolute and relative (i.e., compared to other countries) terms, private-sector investment in agriculture R&D domestically has been waning. For example, Canada was found to rank only 25th in the world in 2014, having fallen from 18th place just six years prior, and was ranked 29th in a global competitiveness survey carried out by the World Economic Forum (2016). Matching similar patterns seen in the public sector, the private sector was found to be reducing its own in-house R&D, particularly in the food-processing sector compared to other aspects of manufacturing in Canada. The OECD (2015) report identified a need for additional sources of venture capital as this type of funding is critical for innovating firms, while also recognizing that under our current system, the prime beneficiaries of tax rebates for R&D in Canada are larger firms. Improved targeting of these rebates could increase their effectiveness.

It is therefore clear that for a variety of reasons that may be endemic to countries other than just ours, a priority must be to encourage greater levels of private-sector investment in Canadian agricultural innovation. There are at least three obvious methods for doing so:

- Ensuring the regulatory environment is conducive to private investment, largely through a reduction in red tape and a commitment to ensure relative federal and provincial government agencies are efficient and entrepreneurial in their approach to dealing with private-sector partners;
- Implementing a system of financial incentives that ideally both subsidizes the direct cost of investments and provides tax relief in the form of credits and/or reduced tax rates; and
- Creating a system that will allow private investors to realize a steady share of the long-term benefits of the investments they make by protecting their intellectual property rights (IPRs). Alston et al. (2012) in particular note the success of end-point royalties (EPRs) in other jurisdictions and advocate for their increased use in North American agriculture.

A third common theme among previous explorations of the Canadian agricultural innovation system, and a very positive one, pertains to the steady output of Canadian scientists, measured both in terms of patents and publications, at the university as well as federal and provincial government levels. The AIC (2017) reports that from 1997 through 2014, Canada ranked eighth worldwide in terms of both production of research papers in the agricultural sciences and average relative impact factor, and 16th overall in terms of its average of relative citations. Of scientific papers produced, about three-quarters came from post-secondary institutions, another fifth from the federal government and the remainder from (mostly) provincial government researchers followed by scientists in private-sector and non-profit organizations. The OECD (2015) report noted that the Canadian agricultural innovation system performs well, producing a good number of scientific publications and patents to go along with new variety/cultivar development.

Aside from those major common threads, the recent significant studies also had unique observations pertaining to our system. For example, the OECD (2015) paper touched upon the politically sensitive topic of supply management in Canada, suggesting that these systems remove some incentives to become more efficient through innovation. That work also noted that recent frameworks for Canadian agricultural policy — Growing Forward 1 and Growing Forward 2, followed by the Canadian Agricultural Partnership — have increased direct incentives for innovation and promote greater co-operation between the public and private sectors. The AIC (2017) report noted that despite the potential for farmers to benefit enormously from new digital technologies, limited rural broadband service and the lack of a common analytics platform hinder greater uptake of these technologies. That report also advocated for the adoption of a more inclusive and participatory system of agricultural innovation in Canada.

Last, prior studies have of course concluded with recommendations to improve agricultural innovation in Canada that have both similarities and differences. The OECD (2015) paper observed that in terms of the policy environment for innovation, improvement could be made by simplifying and modernizing regulations, creating conditions that would facilitate the addition of skilled labour to the workforce, providing additional venture capital and fostering greater use of information and communication technology. The report then summarized four key areas for policy recommendations:

- Improving incentives for private investment;
- Enhancing capacities and services for innovation;

- Removing impediments to innovation that may be unintended but hinder structural adjustments and hence investments; and
- Boosting the direct incentives to agri-food sector innovation.

Recommendations from the later AIC (2017) report focused on encouraging additional private, business-led investment in order to generate improvements in agricultural productivity growth. Methods suggested for doing so include ensuring intellectual property rights are respected while also providing tax credits and other financial incentives for investment, especially if they are targeted to small and medium-sized enterprises (SMEs). Facilitation of strategic business alliances and greater levels of P3 and/or P4 partnership arrangements are also suggested. The AIC (2017) report also highlighted the Dutch agricultural innovation system, which it argues became tremendously successful through a combination of working with agri-businesses to develop a strong set of incentives for private-sector investment and the establishment of thriving innovation hubs which bring together the private and public sectors along with university scientists. Last, they note the importance of continuing to provide strong support for basic research, which is the foundation upon which further innovation is constructed.

Though much of the above discussion has focused on policy, activities and funding amounts at the federal level, no description of Canada's agricultural innovation system would be complete without an acknowledgment of provincial governments' policy and programming. What follows is a brief province-by-province overview of a subset of the agriculture innovation initiatives currently in place.

British Columbia: Canada's westernmost province is home to more than 150 agri-tech1 companies focusing on technologies over a wide range of agricultural activities (British Columbia Government 2023). Innovation and technology programs supported by the provincial government include the Canada-BC Agri-Innovation Program (joint programming from the two senior levels of government), the Agriculture Venture Acceleration Program and the Regional Innovation Ecosystems Program. The BC Food Hub Network and Innovate BC are other resources available to facilitate innovation in British Columbia. Also, Simon Fraser University hosts the BC Centre for Agritech Innovation, dedicated to providing matching funding, project support and partnership opportunities for commercialization to innovating SMEs (BCCAI 2023).

Alberta: principle research and innovation agency for Alberta is Alberta Innovates, established more than 100 years ago as the Scientific and Industrial Research Council of Alberta (SIRCA) (Alberta Innovates 2023). The agri-food sector initiatives supported through this agency target productivity increases for the sector in a sustainable way, with reductions in both input use and emissions as key goals. Areas of focus include innovations for the food-processing sector, biotechnology, autonomous systems/robotics, digital/data solutions and prion research. Funding opportunities for innovators include the Agri-Food and Bioindustrial Innovation Program (ABIP) and the Chronic Wasting Disease Research Program. Alberta Innovates is also a member of the Agriculture Funding Consortium and was instrumental in establishing the Canadian Agri-Food Automation and Intelligence Network.

Saskatchewan: Given its rich agricultural industry and vast farmlands, it's not surprising that this province has a number of supports in place for agricultural innovation. The provincial government's main innovation agency is Innovation Saskatchewan, whose mission is to support Saskatchewan's research community and technology sector to create economic growth and

[1] Agri-tech is defined as "The fusion of innovation and technology applied to the agriculture, food processing and seafood sectors" (British Columbia Government 2023).

diversity (Innovation Saskatchewan 2023). Its support for agricultural innovation comes principally through the Agtech Growth Fund, designed to accelerate commercialization of innovations in Saskatchewan's agricultural sector. Support for R&D is targeted to the areas of digital agriculture software and hardware; smart farm equipment, including robotics; the supply chain (traceability); the agricultural marketplace and financial technology; and animal health.

The University of Saskatchewan hosts Agtech Research, billed as a technology hub boasting world-class facilities and researchers (University of Saskatchewan 2023). The range of the university's innovation activities through Agtech and associated initiatives is broad and deep, often involving government, university, the private sector and producers. Successful startups accredited to efforts through Agtech include ABAzyne BioScience Inc., Indigo Ag and Prairie Tide Diversified Inc. Saskatchewan has several additional resources supporting innovation; they include, but are not limited to, the Agriculture Development Fund and the Agriculture Demonstration of Practices and Technologies (ADOPT) Program (Saskatchewan Government 2023). Last but not least, the Agri-Food Innovation Centre (also located on the University of Saskatchewan campus) has a mandate to assist food processors and agri-businesses to commercialize innovative food products and ingredients (AFIC 2023).

Manitoba: The Keystone Province has a number of initiatives targeted to research and innovation, including the Agriculture Innovation Hub (AIH) and funding under the joint federal-provincial Sustainable Canadian Agriculture Partnership (Manitoba Government 2023). In May 2023, the federal and Manitoba governments committed to $65 million in funding over five years. The AIH provides $3 million annually to foster collaboration among industry members, academics and the provincial government to help grow both crop and sustainable protein production as well as grain handling and utilization innovations. Other significant innovation incubators include the Grain Innovation Hub and Assiniboine Community College's Prairie Innovation Centre for Sustainable Agriculture.

Ontario: Addressing and mitigating climate change, disease spread and pest management, improving competitiveness, responding to consumer demand and growing the agri-food sector sustainably are the many focuses of innovation programming in Canada's most populous province (Ontario Government 2023). Researchers in the agricultural sciences at the University of Guelph are eligible for funding under the Ontario Agri-Food Innovation Alliance, a partnership between that institution and the provincial government. Support is also available through the Ontario Agri-Food Research Initiative, whose most recent call for project proposals focuses on applied research, pilot activities and demonstrations and commercialization of innovations. Ontario also developed the Agri-Tech Innovation Cost-Share Program to support development of innovations (examples include robotics and increased levels of automation) designed to enhance worker health and safety during the COVID-19 pandemic (OMAFRA 2023).

Quebec**:** A major innovation centre in this province is the Centre for Technological Innovation in Agriculture (CINTECH), whose mission is to improve innovation and competitiveness in agriculture and biofoods through the support of R&D, technology transfer and consumer research (Réseau CCTT 2023). Innovation in sustainable agriculture is the mission of the Research and Development Institute for the Agri-environment (IRDA) in Quebec, with support for activities in the crop, livestock, fruit and market gardening sectors (IRDA 2023). Major initiatives supported by IRDA have heavily focused on the environment and the impacts of nutrient loads on the health of both soil and waterways. The Centre d'innovation sociale en agriculture (CISA) focuses heavily on technology transfer of innovative social practices, using an interdisciplinary approach that can involve agro-economics, anthropology, agro-forestry, sociology, the environment and territorial development (CISA 2023).

Atlantic Canada: Each of Canada's Atlantic Provinces has programming targeted to innovation in the agri-food sector. New Brunswick's Enabling Agricultural Research and Innovation (EARI) program is designed to encourage growth, sustainability and profitability in all elements of the agriculture sector in that province. New innovation opportunities, industry-led R&D, pre-commercialization and pilot projects, commercialization, technology transfer and new technology development are all eligible for support through this joint federal/provincial Sustainable Canadian Agricultural Partnership-funded program.

The Nova Scotia Innovation Hub has a strong sustainability focus, working to support innovation in the bio-economy of that province with a focus on transitioning to a low-carbon future. The hub has worked in (among others) the food and agriculture sector with firms such as ZeroIN Foods (sugar alternative), DeNova (sustainable protein company), Mara Renewables (high omega-3 algal oils), Smallfood (alternative protein sources), Outcast (upcycled protein powder) and Maskwiomin (Mi'kmaw skincare remedy) (NSIH 2023). Like other provinces, Nova Scotia has also partnered with the federal government through the Sustainable Canadian Agricultural Partnership, having received a five-year commitment of $46.25 million in the spring of 2023. As with other provinces, research and innovation toward sustainability figure prominently into programming under this initiative in Nova Scotia.

Prince Edward Island: The Agriculture Research and Innovation Program supports innovation, technology adoption and applied research projects targeted to the farm level, with the goal of enhancing competitiveness, productivity and profitability in that province's agri-food sector (Prince Edward Island Government 2023). Within that program, the Agriculture Technology Advancement Sub-Program in particular is targeted to new technologies, adaptation of existing technologies, adoption of new best on-farm practices, knowledge transfer and the demonstration and evaluation of innovations. As with other provinces, the Sustainable Canadian Agricultural Partnership provides support for the program.

Newfoundland and Labrador: The Agriculture Growth and Innovation Program is part of a broader family of Atlantic Canada Business Grants. The program's goal is to quicken the pace of innovation in agriculture in Newfoundland and Labrador in order to enhance growth, productivity, competitiveness and resiliency in the sector (ACBG 2023). Projects targeted for support through this program include aspects of development, knowledge transfer and information for controlled environment agriculture as well as production systems in the crop, livestock, apiculture and fruit industries. Support is also available for information sharing and technology transfer activities. Once again, this provincial program is supported through the Sustainable Canadian Agricultural Partnership.

IMPACTFUL AGRICULTURAL INNOVATIONS IN CANADA

There are many opinions regarding the innovations that have been most important in the agri-food sector; every stakeholder has unique perspectives and each sees the world through the lens of her own experiences. This paper undertook a micro-survey of a subset of agricultural industry stakeholders to elicit a sufficiently encompassing set of opinions. A class consisting of 15 undergraduate students (exclusively agriculture majors), a number of agri-food industry professionals and current agricultural producers — both newer as well as more experienced — were asked to identify the innovations they considered to be the most critical for the advancement of not only their industry, but of society in general. The youngest survey participants were a little under 20 years old, while the oldest was an agricultural producer from Saskatchewan still thriving in his eighth decade and still managing daily a mixed farm

with more than 3,000 acres and more than 200 head of cattle. While there were commonalities among all or nearly all of the responding stakeholders, there were also significant differences relating to the respondents' unique lived experiences.

The following points are excerpts from survey responses when agri-food industry stakeholders were asked to share their perspectives on the most important agricultural innovations of their lifetimes:

- Crop breeding and genetic modification have led to not only higher yields, but also reduced pesticide use and lower costs/greater profitability for farmers;
- Synthetic fertilizers to help optimize land use and produce more food; modern refinements such as dry dispersible powder (DDP) micronutrient fertilizers help target specific nutrients to an array of applications;
- Genetic improvements and cross-breeding of cattle have allowed the most desirable animal traits to be brought into my herd, matching my farm setup and management practices;
- An ever-evolving array of pesticides/herbicides provides conditions that allow crops to thrive to the greatest extent possible;
- Beneficial crop rotations and tillage practices to maintain plant and soil health have made a difference to my farm and my parents' and grandparents' farms before me;
- Soil testing to optimize nutrient management is critical to give crops the best chance to succeed while also contributing to sustainability by not over-fertilizing;
- Improvements in ensuring animal health, including but not limited to, better vaccines and antibiotics that keep my herd healthy and help them fight off infections during our cold winters and wet springs;
- GPS/autosteer helps efficiency by minimizing the number of passes, which in turn also enhances sustainability through reduced fuel, fertilizer and herbicide use;
- Improvements in the scale of mechanization, from horse-drawn plows and threshing machines to 50-foot air seeders and combines that can harvest up to a half-section per day in ideal conditions have allowed me to compete with producers around the world;
- Moving to round bales from square bales was one of the biggest game-changers in the cattle industry as feed waste was dramatically reduced;
- Use of drones for crop scouting minimizes the need to drive over crops, helping ensure crop losses are minimized while also saving fuel use to enhance sustainability;
- Advances in transportation (advent of larger capacity trucks, use of trains to get grain to port, etc.) have increased efficiency. Scale has reduced emissions per tonne of output;
- Improvements in both communication and the dissemination of market information have increased competition among processors/purchasers while ensuring producers stay informed of the best opportunities to sell their commodities;
- Artificial intelligence (AI) is making huge inroads in agriculture — building upon the thinking that brought us GPS and IoT (Internet of Things) advancements. There are now prototypes for self-driving planting and harvesting equipment, autonomous sprayers and increasing use of many types of robots in agricultural applications;

- Innovation in the proper use of policy mechanisms has been important for agriculture. Providing meaningful options in support of risk management and revenue insurance that meet international obligations are efficient from a public policy perspective and are still effective when required, is important to the sector;
- Growth-enhancing technologies in the cattle feeding sector have increased feed efficiency and reduced feedlot turnover times;
- Irrigation has been around for thousands of years (originally trenches) but modern applications of drip irrigation are effective and minimize water use, enhancing sustainability;
- Some of our most experienced producers have seen the progress of mechanization from farming with horses to self-driving tractors occur during their lifetime.

Common themes emerge from the above stakeholder observations as to the innovations that are perceived to have been the most impactful for agriculture in Western Canada; these will be explored in turn below, with a general overview of the innovation and its importance to Canadian agriculture.

GENETIC MODIFICATION OF CROPS

Many observers consider gene manipulation to be the single most important innovation in the history of agriculture and it is not hard to see why they would think so. Few innovations have done more to increase yields, make crops more resistance to pests (be it insects or weeds) and improve farm profitability than GM crops. While some observers do express concerns about the safety of such crops — for example, the European Union has banned GM crops since their inception — it is generally agreed that a reduction in the amount and variety of pesticides used due to the widespread adoption of GM crops has resulted in improved sustainability for the grains sector.

Given the prevalence of GM crops and the range of opinions surrounding continued (some would say politically motivated) hesitance to their universal adoption, it is not surprising that the economic and environmental sustainability of these crops has been the subject of many studies over the last 25 years or so. Klumper and Qaim (2014) conducted a meta-analysis of 147 agronomic and/or economic studies focusing on herbicide-tolerant soybeans, maize (corn) and cotton, comparing yield, amount and/or cost of pesticide used, total production cost and enterprise profitability. They discovered that genetic modification has increased yields by 21 per cent due to reduced crop damage as a result of increased pest control; that pesticide use was reduced by an average of 37 per cent,[2] yielding a pesticide cost savings of 39 per cent; and that profitability was increased by an impressive 69 per cent for GM crop adopters compared to non-adopters. Overall, the study concluded that the average economic and agronomic gains from GM crops are considerable.

[2] A reduction in pesticide use was only discovered for insect-resistant (IR) GM crops. Herbicide-tolerant (HT) GM crops experienced no reduction in pesticide use on average for the studies included in the meta-analysis. Similarly, IR crops experienced a profitability increase as a result of GM adoption. For HT crops, the profitability increase was of a similar magnitude, but was more highly variable and not statistically significant, possibly due to a much lower number of such studies included in the meta-analysis.

ADVANCES IN AGRONOMY

Aside from the advent of genetically modified crops, innovations in farming have facilitated a dramatic increase in the amount and quality of food produced by the Canadian agri-food sector over the last several decades. A good deal of this increase is due to improvements in agronomic practices; one very big-picture example of this is the large-scale abandonment by Prairie farmers of the practice of summerfallowing. Under this practice, as much as half of a producer's land would remain fallow (i.e., not have a crop sown upon it) in any given crop season. As agronomists (mostly soil and crop scientists) recognized that contrary to the long-held belief that "resting" a plot of land would provide some kind of mystical regenerative benefit, this practice was in fact contributing to soil erosion, increasing soil salinity and resulting in a loss of both soil moisture and soil nitrogen. Extensive research and subsequent education efforts were made toward the practice of continuous cropping. Spicer (2009) estimates that as recently as 1991, as many as 20 million acres were being summerfallowed in Canada. For 2023, acres under fallow were reported to be only 1.319 million (Statistics Canada 2023b) — a reduction of around 95 per cent in the last 30 years. This reduction has helped lead to historic seeded acreages of field crops. As Figure 3 shows, in 2023 Canada had its highest-ever areas seeded to principal field crops, of just under 74 million acres.

Figure 3. Total Seeded Acres, Principal Field Crops in Canada, 1908–2013

ADVENT OF LARGE-SCALE CATTLE FEEDING OPERATIONS

Though cattle were introduced into southern Alberta in the 1860s, the first large-scale feedlot in Western Canada did not arrive until nearly 100 years later in the late 1950s, when Western Feedlots was constructed at Strathmore, Alberta (Neilson and Prociuk 1998). Subsequent agreements between cattle owners and other farmers and landowners recognized the synergies available given the resource needs of livestock feeding and the availability of grain/forage, pasture and labour provided by local communities. This resulted in the rapid expansion of large-scale cattle feeding in southern Alberta (ACFA 2023). Since that time, the Alberta feedlot sector has been a success story in the Canadian cattle industry, helping ensure a steady supply of fed cattle that supports two major beef processing plants in the region (Cargill at High River and JBS at Brooks) that provide beef for Canadians, as well as exporting to the U.S. and dozens of other countries around the world. The driving factor behind the success of the cattle feeding industry in southern Alberta is the realization of economies of scale, which simply means that as the scale of an enterprise increases, fixed costs are spread out across more units of production, reducing the fixed cost per unit of production. In addition to economies of scale in minimizing cost, there are returns associated with being able to provide a steady volume of cattle with relatively uniform size and quality. Larger scale feedlots can do this and processors value this ability as it reduces their operating risks.

Economic benefits resulting from this innovation extend beyond the private returns to cattle feeders and processors. Upstream from cattle feeders, the presence of stable demand for their feeder calves provides benefits to ranchers and backgrounders who are assured there will be a place for their animals at a price that reflects market conditions for beef. Downstream, consumers of beef — a staple food in the diets of millions of Canadians and hundreds of millions more around the world — benefit from a safe, reliable supply of protein they are assured is from a reputable source. It is therefore fair to say that not only has the innovation of the modern large-scale cattle feeder in Alberta benefited many stakeholders along the beef supply chain, but consumers have also benefited from, and become accustomed to, the availability of affordable, safe Canadian beef as a result.

ECONOMIC AND SUSTAINABILITY IMPACT OF INNOVATIONS

Innovations in agronomic practices, technology, farming practices and all other relevant areas have created enormous benefits for agricultural producers, processors and other stakeholders in Canada and around the world. It has been widely recognized that innovation in agriculture is critical to meet the ever-increasing nutritional requirements for a burgeoning world population. At the same time, there are concerns about the environmental impacts of modern agricultural practices, and so innovators in the agricultural sciences have a social responsibility to consider their work in the broader context of sustainability (Sayer and Cassman 2013). Some researchers have predicted that given the relationship between per-capita income and per-capita caloric consumption, global crop demand will at least double by 2050 (Tillman et al. 2011), and note that meeting this demand sustainably (i.e., by avoiding excessive transitioning of land into agricultural production) will depend critically upon the development and dissemination of high-yielding technologies and continued innovation in both farming tools and management practices.

Burney et al. (2010) found that during the 44-year period between 1961 and 2005, greenhouse gas (GHG) emissions from factors including fertilizer production and application have increased and the development of higher yielding crops has avoided more than 160 gigatonnes of carbon emissions. The authors further concluded that investments in improved yields pay off significantly.

They estimate that each additional dollar invested in agricultural technology has led to a 68 kgC (kilograms of carbon) reduction of emissions compared to 1961 technology.

As noted earlier in this paper, one of the most important innovations in agriculture in the last half-century has been the genetic modification of crops. Barrows et al. (2014) note the inherent advantages to improving crops through genetic modification compared to slower, more cumbersome traditional plant-breeding methods. The economic impacts of GM crops have been enormous. For example, Brookes and Barfoot (2020a) estimate the global value attributable to the use of genetically modified crops between 1996 and 2018 to be over US$225 billion, the majority (52 per cent) of which has accrued to farmers in developing countries. Those researchers found that farm income in Canada was enhanced by more than $8 billion between 1996 and 2016 alone. A later update to these totals by Brookes (2022a) found an additional $36 billion had accrued to farmers worldwide in the ensuing four years, with cost savings from GM crop use in Canada approaching $21/ha^{-1} for soybeans and $58/$^{-1}$ for canola. No less important have been the overall worldwide farm income gains from the use of herbicide-tolerant canola, which for the 1996–2018 period are estimated at over $8 billion, 75 per cent of which comes from yield improvements, with nearly all of the remainder deriving from cost savings. Paarlberg and Smyth (2023) note the significant contributions of biotechnology to accomplishing improvements in food supply, farm incomes and sustainability through reduced use of pesticides, and Kovac et al. (2022) observe that GHG emissions in the EU could be reduced by as much as 7.5 per cent with a wider adoption of GM crops. Brookes (2022b) and Brookes and Barfoot (2020b) further explore the environmental impacts of GM crop use.

AGRI-FOOD INNOVATION 2050: A PATH FORWARD

As a world leader in building a sustainable, profitable and safety-oriented agri-food system, Canada is uniquely positioned to establish itself as a pre-eminent hub for innovation. However, this will require a significant commitment by senior government levels. The following are three key cornerstones upon which the foundation for a thriving climate for agricultural innovation in Canada can be constructed.

1. A commitment to invest in Canadian agricultural innovation at 0.10 per cent of GDP

Several studies have concluded that investments targeted to innovation in agriculture tend to have very high rates of return. While cautioning that overstatement of internal rates of return (IRRs) to R&D and a general lack of understanding of how to interpret these numbers in the context of returns to research (versus, say, the context of returns to financial investments) tend to give an inflated sense of real returns to expenditures on R&D, Hurley et al. (2016) nevertheless report very high returns to investments in research. Like many observers, they are puzzled by the downward trend in expenditures in this category, given the significant positive benefits. For example, expenditures on agricultural innovation in Canada have declined by roughly 70 per cent since 1986 (AIC 2017). Given this downward trend, the sector has a clear choice to make — if it wishes to remain near the forefront of sustainable innovation among competitor nations, there must be a significant commitment to increase investment in these activities. In a thorough investigation of innovation policy in the canola, wheat and pulse sectors in Canada, Malla and Brewin (2020) advocate strongly for public support of basic research as well as subsidization of R&D costs for firms.

2. Stimulation of private-sector investment in innovation

According to Statistics Canada (2017), the ratio of Canada's business enterprise expenditures on research and development (BERD) to GDP (0.85 per cent) was slightly more than half of the OECD average (1.61 per cent) in 2013. With private-sector investment and relationships with federal, provincial and post-secondary partners critical to innovation, it seems clear that there is an urgent need to stimulate more investment in this area, particularly given the threat of reduced public funding, despite clear evidence that returns to research are high and extremely important to competitiveness. AIC (2017) notes that despite having a comparable increase in scientific production in agriculture to Canada between 1997 and 2014, the Netherlands ranks first in the world in terms of the scientific impact of its agriculture research, while Canada ranks 16th. Reasons for this are said to be the Netherlands' focus on encouraging a high level of private-sector investment in agriculture R&D, its commitment to supporting intensive production facilities, its establishment of thriving hubs for agricultural innovation and its efforts toward high-quality agricultural workforce education.

3. Enhancement of protection for intellectual property rights

As noted above, private-sector investment in R&D is critical to spurring innovation in agriculture. However, private investors are sometimes hesitant to make such investment without assurances that their intellectual property will be protected; i.e., that they will be able to realize long-term financial benefits from their innovations. Alston et al. (2012) noted more than a decade ago that an emphasis on private R&D investment has been placed upon a set of technologies, crops and farming/mechanical innovations that are attractive from an IPR protection perspective. Lamenting the dearth of R&D targeted to increased farm productivity, after extensive exploration of agricultural innovation policies around the world, the authors made two major policy recommendations. First, they suggested end-point royalties (EPRs) as a method of establishing and enforcing IPRs. These royalties, collected at point-of-first-sale or commercial use, are in place for around 250 grain and pulse varieties in Australia (Variety Central 2023). The second recommendation was the implementation of additional commodity levies (i.e., check-offs) which in conjunction with matching government grants would be used to fund research directed by the commodity organizations administering the funds. Although Agriculture and Agri-Food Canada has begun studying the feasibility of royalty payments for farm-saved seed (Lassoued and Smyth 2022), no significant improvement to this trend has been seen in the years since that work was carried out (Gray 2023). Thus it is more important than ever to strengthen IPR across a host of agricultural innovation targets to spur greater levels of investment in these areas. Moreover, Alston et al. (2012) lament the lack of private and public-sector investment in a number of areas of agricultural R&D that focus upon improvements in farm productivity, including most of the livestock sector (the beef industry is important in Western Canada), as well as improved varieties of feed grains. By contrast, crops with relatively stronger IP protection see greater investments in R&D. The OECD (2015) estimates that just three crops (canola, corn and soybeans) attract 95 per cent of private-sector crop breeding investments in Canada.

CONCLUSION

Agricultural innovation over the last many decades has provided Canada with a thriving, dynamic agri-food system that is among the world's leaders in providing an abundance of safe and nutritious food. Recent investigations of the challenges and opportunities have provided high grades for Canada's system of agriculture innovation, but also identify challenges as levels of public funding continue to decline and the need for higher levels of private-sector investment become increasingly clear. Canada has worked hard to earn a well-deserved reputation as a centre for research and development in the agricultural sciences, but maintaining this high standing will require further commitments by senior levels of government.

Creating optimal conditions for renewed energy in Canada's agricultural innovation system is complex, yet straightforward. All studies of this country's innovation system draw virtually the same conclusions — that public-sector support cannot continue to decline and must in fact be restored to previous (higher) levels and that incentives for the private sector to invest, using tools such as tax relief, matching funds and greater protection of intellectual property rights, must be strengthened. The recommendations themselves are, of course, the easy part.

The challenging part is actually bringing these policy recommendations to fruition. All levels of government would doubtless love to provide greater levels of public funding for agricultural innovation. The need to do so, given concerns about food security the world over, and farm incomes here at home, could not be clearer. However, competing budget priorities make it difficult for governments to make these investments as a multitude of stakeholders all clamour for additional support, each with a compelling case as to why their cause should be moved to the front of the line. Governments are thus challenged to choose among a number of worthy causes when deciding which priorities to support.

Even with these challenges, Canada is well-positioned to maintain its status among the globe's leading countries for agricultural innovation. While lower than historical levels, public-sector funding levels are still significant and are being effectively targeted, according to most observers. Policy-makers continuously seek ways to improve the regulatory environment to encourage innovation and collaborations between the public and private sectors. University scientists churn out research at a furious pace, developing new and improved crops and animal genetics and showcasing their work through scientific publications and presentations. Overall, Canada can be very proud of its innovation record in agriculture. With effort, we can continue to be among the world's best in this regard.

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ISSN
ISSN 2560-8312
The School of Public Policy Publications (Print)
ISSN 2560-8320
The School of Public Policy Publications (Online)

DATE OF ISSUE
January 2024

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