Crunching the numbers: A snapshot of Canada's agricultural technology landscape

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A report prepared for *Remote controlled: The impacts of disruptive technologies in the Ontario agriculture sector*

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About the Project

This report is part of the *Remote controlled: The impacts of disruptive technologies in the Ontario agriculture sector*, which was designed to understand the impacts of disruptive technology adoption, including the scope of technologies that could disrupt traditional production practices and the future of work. For more information, please visit our project website.

An earlier version of this work was presented at the Northern Directions Conference of the Canadian Rural Revitalization Foundation (CRRF) on November 18, 2022 and the Canadian Association of Geographers – Ontario Division (CAGONT) Conference on October 28, 2023. We are grateful for the feedback provided by the conference participants.

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Executive summary

The Canadian agriculture sector has entered a transformational phase where the application of digital technologies, like automation, data analytics, precision agriculture, artificial intelligence (AI), and robotics, has created the potential to reshape on-farm labour and food production across Canada. Despite the promise of digital agriculture in Canada, little is known about the Canadian organizations producing digital agricultural technologies. Moreover, there is limited academic and policy research that examines agricultural technology firms in Canada, the location and characteristics of these firms, or if the technologies developed by these firms are positioned as enabling business, environmental, and social benefits.

In this report, we address three key questions:

1. What are the characteristics of Canadian agricultural technology organizations?
2. What business, environmental, and social benefits do Canadian agricultural technology organizations emphasize?
3. Is there a relationship between the gender diversity of leadership teams, innovation outcomes, and a focus on sustainability?

To answer these questions, we assembled a novel dataset of organizations headquartered in Canada that produce digital technologies for the agricultural sector. To do so, we identified organizations using Crunchbase, a digital platform that provides information about private and public organizations, including firm characteristics, investment and funding, founding members and individuals in leadership positions, mergers and acquisitions, news, and industry trends.

We identified organizations classified as 'Agriculture' on the Crunchbase platform and that had headquarters in Canada, and that met the following additional criteria:

- The organization was Canadian-owned;
- The organization had active business operations; and
- The organization was developing digital technologies with specific applications in the agricultural industry.

Based on information from the organizations' Crunchbase profile and their website, we identified 247 organizations that met these criteria. For these 247 organizations, we analyzed and coded information available from Crunchbase, as well as collected and coded supplementary information from the websites of these organizations to develop variables that captured a range of characteristics. These characteristics included the organization's headquarter location; the type of organization, its size and structure; the composition of its leadership team; areas of application within agriculture; the types of technologies under development; and the intended business, environmental and social benefits of the technologies.

Characteristics of Canadian agricultural technology organizations

Based on our analysis of our database, we found the following:

- The majority of agricultural technology organizations are small to medium sized businesses with fewer than 50 employees;
- More than two-thirds of agricultural technology organizations have annual revenues of less than $10 million (CAD);
- More than half of Canadian agriculture technology organizations were founded in the last ten years;
- Over four-fifths of agricultural technology organizations are headquartered in Canada's metropolitan areas;
- Over two-thirds of Canadian agricultural technology organizations hold registered patents and registered trademarks;
- The majority of Canadian agricultural technology organizations are engaged in creating equipment, platform and software-based solutions
- A range of enabling technologies are used by Canadian agriculture technology organizations including: software and cloud-based software services, connected devices, remote sensing, biotechnology, artificial intelligence or machine learning (AI/ML) technologies, and next-generation (NextGen) farm technologies for indoor controlled environment automation;
- In-field applications predominate, but organizations are also involved in creating technology solutions for livestock and indoor controlled environment systems; and
- The majority of Canadian agriculture technology organizations are designed for a specific commodity, with animals, principal crops, and vegetable crops each accounting for roughly one-quarter of organizations.

Business, environmental, and social benefits

Given that there is an increasing interest in sustainability in the agricultural sector, we sought to understand the business, environmental and social benefits associated with the digital agricultural technologies produced by Canadian organizations. The most commonly featured business benefits were:

- labour savings;
- enhanced decision making;
- increased output;
- reduced production costs;
- improved quality of commodity products; and
- pest/disease management.

These benefits were consistently the most cited by agricultural technology organizations across Canada's regions and in both urban and rural locations.

The most addressed environmental and social benefits included:

- water conservation;
- reduced pesticide use;
- general or non-specific sustainability benefits;
- improved livestock health and safety; and
- reduced fertilizer use.

Most of these benefits address environmental concerns rather than social issues. We found limited differences across Canada's regions and few differences between urban and rural areas in terms of which benefits were emphasized.

We found that Canadian agriculture technology organizations generally position the environmental and social benefits of their products as distinct and separate from business benefits, rather than as synergistic or complementary advantages. Other findings included:

- All organizations communicated the business benefits of their technologies;
- Less than two-thirds of Canadian agriculture technology organizations mentioned environmental and social benefits, but there was regional variation:
    - Less than half of agricultural technology organizations in Western Canada emphasized environmental and social benefits;
    - Almost two-thirds of organizations in Central and Atlantic Canada emphasized environmental and social benefits.
- Almost two-thirds of organizations headquartered in urban areas were sustainability-focused compared to less than half of organizations headquartered in rural areas.

Sustainability, innovation and the gender diversity of leadership teams

Finally, we explored the leadership teams of Canadian agricultural technology organizations to understand the extent to which these organizations have embraced gender diversity in their leadership. Several key findings emerged:

- Slightly more than half of Canadian agricultural technology organizations have exclusively male leadership teams;
- There were similar proportions of all-male leadership teams in urban and rural areas;
- Rural-based organizations had higher proportions of women in leadership roles and there was a slightly higher proportion of all-female leadership teams in rural areas compared to organizations headquartered in urban areas;

Nonetheless, there remain low levels of gender diversity across leadership teams in agriculture technology organizations, which mirrors traditional sectors in Canada.

We further explored if there is a relationship between gender diversity in senior leadership and innovation, as well as an emphasis on wider sustainability benefits (rather than business-only benefits) associated with the organization's digital agricultural technologies.

- There were limited differences based on whether an organization promoted broader sustainability benefits rather than only business benefits based on the gender composition of their leadership team;
- Agricultural technology organizations with women in leadership roles were more than twice as more likely to own at least one patent;
- Among agricultural technology organizations that own patents, those organizations with gender diverse leadership teams also owned more than double the number of patents on average compared to those agricultural technology organizations with exclusively male leadership teams.

Looking ahead: Opportunities for future research

Overall, our research provides novel insights into the state of Canada's agricultural technology sector. Several observations stand out and that merit further investigation.

- There are substantive variations across Canada's vast geography and between urban and rural areas and these patterns can only be understood through further careful, in-depth research and study;
- The relatively low proportion of Canadian agricultural technology organizations using AI and robotics technologies in their products, especially in comparison to competitor nations, may be an area of policy concern, with downstream implications for the competitiveness and productivity of the agricultural sector writ large.
- Business benefits were emphasized much more than sustainability benefits. This stands in contrast to the growing interest in sustainability across the agricultural sector. This merits further analysis to better understand how sustainability is addressed (or not) in the sector.
- Like many traditional sectors in Canada, the leadership teams of agricultural technology organizations did not reflect gender diversity. However, while we found limited relationships between the gender diversity of leadership teams and a focus on sustainability, we did find higher levels of innovation (measured by patents) among organizations with gender diverse leadership teams. These findings require further investigation to understand if there are ways to further bolster innovation in the agricultural sector.

1 Introduction

The Canadian agriculture sector has entered a transformational phase where the application of digital technologies, like automation, data analytics, precision agriculture, artificial intelligence (AI), and robotics, has created the potential to reshape on-farm labour and food production across Canada. Despite the promise of digital agriculture in Canada, little is known about the Canadian organizations producing digital agricultural technologies. Moreover, there is limited academic and policy research that examines agricultural technology firms in Canada, the location and characteristics of these firms, or if the technologies developed by these firms are positioned as enabling business, environmental, and social benefits.

In this report, we address three key questions:

1. What are the characteristics of Canadian agricultural technology organizations?

2. What business, environmental, and social benefits do Canadian agricultural technology organizations emphasize?

3. Is there a relationship between the gender diversity of leadership teams, innovation outcomes, and a focus on sustainability?

To answer these questions, we assembled a novel dataset of organizations headquartered in Canada that produce digital technologies for the agricultural sector.

To frame our research, we begin by placing Canada's agricultural industry in context and discuss agricultural technology innovation and development in Canada. Following this overview, we describe our data and methods, including the potential limitations of our study. Next, we present the results of our study, structured around three main themes: 1) organizational characteristics; 2) business, environmental, and social benefits; and 3) sustainability, innovation and the gender diversity of leadership teams. Finally, we conclude by summarizing and reflecting upon our findings and their implications for scholars and practitioners interested in innovation in Canada's agricultural sector.

1.1 Canada's agricultural industry in context

The United Nations has called for local businesses to support sustainable intensification of food systems to meet the needs of a growing global population. Supporting local businesses in this endeavour requires increased investment in technology development, agricultural research, and rural infrastructure to enhance agricultural productive capacity (United Nations, 2023). Digital technologies can support new ways of monitoring, assessing, and managing soil, climatic, and genetic resources, while helping regional food systems balance the economic, environmental, and social dimensions of sustainable food production (Basso & Antle, 2020). Technologies related to AI, automation, remote sensing, and digital/big data analysis are being used by leading-edge firms to create new markets and accelerate regional innovation clusters focused on agricultural technologies (Nelles et al., 2023).

The global digital agriculture technology market is expected to reach $22.1 billion (USD) by 2028, increasing at a compound annual growth rate of 9.6 percent (Vantage Market Research, 2022). Despite this potential market opportunity, Canada's share of global investment in key digital agriculture technologies lags considerably compared to other nations, including Israel, Singapore, Japan, the Netherlands, Australia, New Zealand, and the United States (Do et al., 2022). Furthermore, the Canadian farm workforce is aging, and younger generations are not entering into agriculture and farming. As a result, Canada has one of the highest skills shortages in food production compared to other major food exporting nations (Yaghi et al., 2023a). This agricultural skills shortage makes it even more necessary to accelerate the development and adoption of autonomous and mechanized technology solutions on Canadian farms and in the Canadian food and agriculture industries more broadly (Yaghi et al., 2023a).

Some observers suggest that Canada has strong potential to become a global leader in the development of digital agricultural technologies due to the country's broad international market access, long history of agricultural innovation, and its position as a top exporter of key crops (Do et al., 2022). Indeed, technological innovations have contributed significantly to the transformation of Canada's agriculture sector over the last 50 years, strengthening the country's competitive position in agricultural exports internationally. Agricultural innovation is one of the key drivers of economic growth in the sector as it enhances competitiveness while creating new opportunities to meet food security and sustainability goals (AIC, 2017). Canada is now the fifth-largest global exporter of agri-food products, generating export sales of $55 billion (CAD) or 5.7 percent of the total value of world food and agriculture exports (AIC, 2017).

Yet, Canadian investment in agriculture research has slowed at the same time that technological competition has grown from emerging agricultural export countries (AIC, 2017). For example, Canada's climate funding for agriculture is approximately one-third the size of the investments that leading food producers, including the U.S., EU, Australia, and China, provide to their agriculture industries for sustainable intensification of their food systems (Yaghi et al., 2023b). Studies of place-based innovation reveal the need for funding that enables firms to complete much longer innovation cycles than public resources typically cover (Nelles et al., 2023). While business-led innovation is essential to derive value from science and technology advancements, Canada's performance in private research and development (R&D) has weakened compared to key competitors such as Australia and the United States (AIC, 2017). Other nations, like Japan and New Zealand, are deploying national strategies to invest in and accelerate digital agriculture technology innovation, with the goal of intensifying food production in a sustainable manner while also addressing growing gaps in local agricultural skills and labour (Yaghi et al., 2023a).

There is extensive evidence that – on average – Canadian firms invest less on R&D than foreign-owned firms (Statistics Canada, 2023a). In fact, public investments represent the largest source of funding for Canada's agriculture R&D. In 2020, public investments in agricultural R&D reached $450 million (CAD), more than four times the investment made by private sector organizations, which totaled $108 million (CAD) (Yaghi et al., 2023a). By contrast, in the United States, private sector R&D spending outpaces the public sector (Plastina & Townsend, 2023). This stark difference has led experts to call for increased private investment in agricultural R&D (Do et al., 2022).

There is some evidence that private investment is beginning to increase, including by foreign-owned companies seeking to expand their R&D efforts and activities within Canada. For example, as a result of Canada's Agri-Tech Industry foreign direct investment initiative, Roquette (France) made a $17 million (CAD) investment to establish an R&D centre for new plant protein development in Winnipeg, Manitoba; Cultivated B (Germany) invested $50 million (CAD) to build an innovation hub for cellular agriculture in Burlington, Ontario; and Raven Industries Inc (United States) spent $15.1 million (CAD) on an innovation centre for digital agriculture technology in Regina, Saskatchewan (IC, 2023). Although foreign investments may encourage local job creation and economic development, their effects on innovation, technology transfer, adoption and diffusion in Canada remain unclear. The acquisition of new technology resulting from foreign investment is typically constrained by many factors, including trade agreements, intellectual property protections, and the availability of local infrastructure and support services to facilitate the absorption of new technologies (Yu, 2023).

1.2 Agricultural technology in Canada

To enable Canada to grow more food while reducing emissions and mitigating other environmental impacts, it is expected that the Canadian agri-food sector will need to adopt climate-smart agricultural practices and digital technologies (Yaghi et al., 2023a). In particular, digital agricultural technologies may help to reduce emissions from Canada's agriculture sector by up to 40 percent by 2050 (Do et al., 2022). Digital agricultural technologies can offer new approaches for Canadian farmers and growers to enhance efficiency, cut costs, and reduce environmental impact. Overall, these technologies are becoming increasingly important in Canada's agriculture system, which employs 2.1 million people, provides one out of nine Canadian jobs, and generates $134.9B (CAD) or 6.8 percent of Canada's GDP (Government of Canada, 2022).

Although Canada is a major agricultural producer, it is less prominent in the development of digital agriculture innovations. Corporations headquartered in the United States (e.g., Bayer, John Deere) or Europe (e.g., FarmDroid, Lely) have historically been leaders in developing such innovations. To spur sustainable agriculture innovation within Canadian-owned firms, the federal government launched the AgriInnovate Program in 2023, aimed at supporting R&D, commercialization, demonstration, and adoption of new technologies and processes (Government of Canada, 2023). The program operates under the auspices of the Sustainable Canadian Agricultural Partnership (CAP), which seeks to strengthen the competitiveness, innovation, and resiliency of Canada's agriculture and agri-food sector by providing support for science, research, and innovation (Government of Canada, 2023).

At the same time, a range of emerging digital agriculture technologies produced by foreign and domestic technology providers are becoming available in Canada, including sensors, soil sampling, drones, GPS guidance, precision machinery, connected devices, AI, robotics, software and machine learning (ML). These digital technologies can help farmers automate workflows to intensify production (Yaghi et al., 2023a). They also allow farmers to make data-informed decisions about their production systems based on the site-specific characteristics of their fields, facilities, or environments (Bhakta et al., 2019). Overall, digital agriculture technologies may

help increase production yield and improve resource efficiency to support Canada's sustainable development goals (Monteiro et al., 2021; Bhakta et al., 2019).

However, recent studies of technology adoption among crop producers in Canada have found widespread use of basic wireless and cable internet and Global Positioning System (GPS) technologies, but much less use of advanced digital agriculture technologies (Steele, 2017; Mitchell et al., 2020). Similarly, precision livestock technologies, including automated dairy and animal health and welfare monitoring, have seen limited adoption in Canada due to farmers' concerns about the costs and complexity involved in the implementation and use of these technologies (Makinde et al., 2022).

Scholars have also noted that the firms involved in creating digital agricultural technologies may hold a narrow set of values about what constitutes 'good' farming and 'good' technology. As a result, these agricultural technology firms tend to privilege larger-scale and commodity crop farmers in their product designs, including the types of data they select for use in their applications. For example, a focus on agronomic crop data and data mapping limits the use of these agricultural innovations by growers in other regions (Bronson, 2018). Such narrow approaches are typical of technological trajectories that reflect the market (Bronson, 2018), in this case, limiting agricultural technology adoption to only the largest agricultural operations.

In light of Canada's AgriInnovate Program and the increasing expectations for digital technology adoption in Canada's agricultural sector, it is more important than ever to explore the Canadian organizations producing digital agricultural technologies. Moreover, given that the AgriInnovate Program is under the Sustainable CAP umbrella, which prioritizes climate change and environmental issues (Government of Canada, 2023), it is also necessary to investigate the business, environmental, and social benefits these Canadian agricultural technology organizations emphasize.

2 Data and methods

In order to develop a more comprehensive picture of Canadian agricultural technology organizations, we developed a novel dataset of 247 organizations. We identified organizations using Crunchbase, a digital platform that provides information about private and public organizations, including firm characteristics, investment and funding, founding members and individuals in leadership positions, mergers and acquisitions, news, and industry trends. Crunchbase is widely accepted as a data source for studying technology start-ups, their characteristics, and financing within and across countries (Dalle et al., 2017; Spigel and Vinodrai, 2021).

To develop our dataset, we began by identifying 923 organizations classified as 'Agriculture' on the Crunchbase platform and that had headquarters in Canada. Based on an initial analysis of these 923 organizations, it was clear that a large number of these organizations did not necessarily focus on creating digital agricultural technologies. To narrow our analysis to only organizations that were actively involved in the creation of digital agricultural technologies, we developed the following inclusion criteria:

- The organization was Canadian-owned;

- The organization had active business operations; and
- The organization was developing digital technologies with specific applications in the agricultural industry.

To evaluate whether or not each of the 923 organizations met these criteria, we examined both the organizations' Crunchbase profile and their website. We excluded organizations that did not have an active website or had ceased business operations (5.3%) from our analysis. Most notably, while the majority of organizations were Canadian-owned and had active operations in Canada, only 26.8% focused on digital agriculture technology. A large portion of excluded organizations operated in business sectors other than agriculture, such as retail, finance, and industrial chemicals. Other excluded organizations focused on agriculture but did not offer digital products; instead, these organizations specialized in fields like equipment manufacturing, biotechnology, and materials. As a result of applying these criteria, our final sample included 247 organizations.

For these 247 organizations, we analyzed and coded information available from Crunchbase. In addition, we collected and coded supplementary information from the websites of these organizations. We developed variables that captured headquarter locations, the type of organization, its size and structure, the composition of its leadership and management team, areas of application within agriculture, the types of technologies under development, and the intended business, environmental and social benefits of the technologies.

To analyze headquarter locations, we used the postal code of each organization's headquarters address to classify whether the organization was located within a Census Metropolitan Area (CMA) or a rural (non-metropolitan) area outside of CMA boundaries. We classified organizations as belonging to one of six categories: for-profit, non-profit organization, government agency, cooperative, research centre, or other type of organization. We further classified for-profit organizations based on their main activities as an agricultural technology producer, or an intermediary organization offering consulting, sales, or implementation services. Similarly, we classified non-profit organizations as either a non-profit agricultural technology producer or a non-profit intermediary organization. We delineated government agencies depending on the level at which they operated: federal, provincial, regional, or local. We also evaluated information about leadership teams listed in Crunchbase, alongside any additional profiles published on organizations' websites, to determine the numbers of women, men, or non-binary persons in active leadership positions (e.g. boards of directors, president/founder, other c-level executives, etc.).

For each organization, we identified several characteristics related to the digital technology being developed or produced by the organization. First, we identified the type of technology product, as well as the primary enabling technologies that underpinned the digital technology. Product types included platform, software application, web service, consulting service, or equipment. Primary enabling technologies included AI, ML, big data analytics, biotechnology, cloud services or software-as-a-service (SaaS), software and platforms, connected devices, next-generation farms, remote sensing, or robotics. Additionally, we examined whether or not organizations were involved in precision agriculture (PA) by examining if the phrase "precision agriculture" appeared in Crunchbase descriptions or if organizations specifically used the phrase "precision agriculture" in their websites to describe their products or capabilities. All of the

organizations in our dataset that used the term appeared to be producing technologies that align with common understandings of PA. In constructing our dataset, we also found that a small number of organizations produced technologies and capabilities that could be classified or marketed as PA, yet these organizations did not use the term “precision agriculture”. However, we only classified organizations as producing PA technologies if they explicitly used the term.

Next, we identified whether the technology was oriented to one of five application areas: in-field sensors and systems, post-harvest monitoring and efficiency, livestock, indoor controlled environment, or other application area. We also identified the target agricultural commodity, using five broad categories: principal field crops; vegetables; tree fruit; berries; and tree nuts and saps.

Finally, we evaluated statements made by these organizations in their profile descriptions and websites to identify the business, environmental and social benefits associated with these digital agricultural technologies. Business benefits included: enhanced decision making, increased output (production/processing efficiency/yields), labour savings, reduced production costs, improved quality, improved consumer safety (e.g., traceability), improved employee safety (e.g., occupational health and safety for people), improved livestock health and safety, enhanced reputation, increased market share, compliance with regulations, improved climate or frost management, and improved pest or disease management. Environmental and social benefits included: reduced fertilizer use, reduced pesticide use, improved soil health, reduced erosion, sustainable intensification of agricultural production, reduced greenhouse gas (GHG) emissions, reduced energy, conserved water, reduced food miles, enhanced food security, and reduced inequalities.

As with any study, our research approach has some limitations. First, there are potential issues related to data quality. Crunchbase assembles and updates its data from a variety of sources. These sources include a large investor network that submits monthly updates; a community of executives, entrepreneurs, and investors who actively contribute to profile pages; artificial intelligence and machine learning algorithms that validate data accuracy and scan for anomalies or data conflicts; and Crunchbase data analysts who provide manual data validation and curation (Crunchbase, 2023). While data fidelity may vary by individual organization and organizational changes may not be immediately reflected on the Crunchbase platform, we are confident in the overall quality and accuracy of our data. Moreover, academic and policy research on innovation, entrepreneurship and business dynamics use Crunchbase extensively and it is widely accepted as a reliable data source (Dalle et al, 2017; Spigel and Vinodrai, 2021).

Similarly, organization websites may not always reflect the most up-to-date information, status, or characteristics of the organization. Finally, our analysis of the gender diversity of leadership teams relied on visual interpretation of the gender expression of individuals shown in leadership profiles published on organizational websites, when pronouns or other identifying information was not available. Thus, our data may not fully capture gender diversity. Nonetheless, our results provide a more systematic understanding of the agricultural technology innovation and development across Canada.

3 Canada's agricultural technology landscape

Our analysis of Canada's agricultural technology landscape focuses on three broad areas: the characteristics of Canadian agricultural technology organizations; the business, environmental, and social benefits associated with their technologies; and the relationship between organizational structure, gender diversity on leadership teams, and these broader sustainability benefits. Our analysis relies on our final dataset of 247 Canadian organizations that are actively involved in developing producing digital technologies for the agricultural sector. Throughout our analysis, we pay particular attention to geographic differences between urban and rural locations, and across Canadian regions.

3.1 Organizational characteristics

3.1.1 Organization type, size, revenue, and age

Table 1 provides a summary of the key characteristics of Canadian agriculture technology organizations. The majority of Canadian agriculture technology organizations are small to medium sized businesses with fewer than 50 employees (**Table 1**). Organizations tend to have small revenue streams, with more than two-thirds generating annual revenues of less than $10 million (CAD). We found that Canadian agriculture technology organizations are relatively new, with more than half of the organizations in our study being founded in the last ten years. However, there are some more established agricultural technology organizations; 16.5% of organizations were founded prior to 1993. It is also clear that the majority of organizations (91.6%) are for-profit businesses, alongside some Canadian research centres, non-profits, and government organizations. Among for-profit businesses, the majority are involved in the development of agriculture technologies, but there are also organizations involved in sales, consulting and implementation.

Since the majority of Canadian agriculture technology organizations are relatively new or small, they may be able to better respond to evolving market conditions and more readily meet specific customer needs. However, these organizations may also be challenged to invest in longer-term R&D or compete against large, established firms.

3.1.2 Headquarter locations

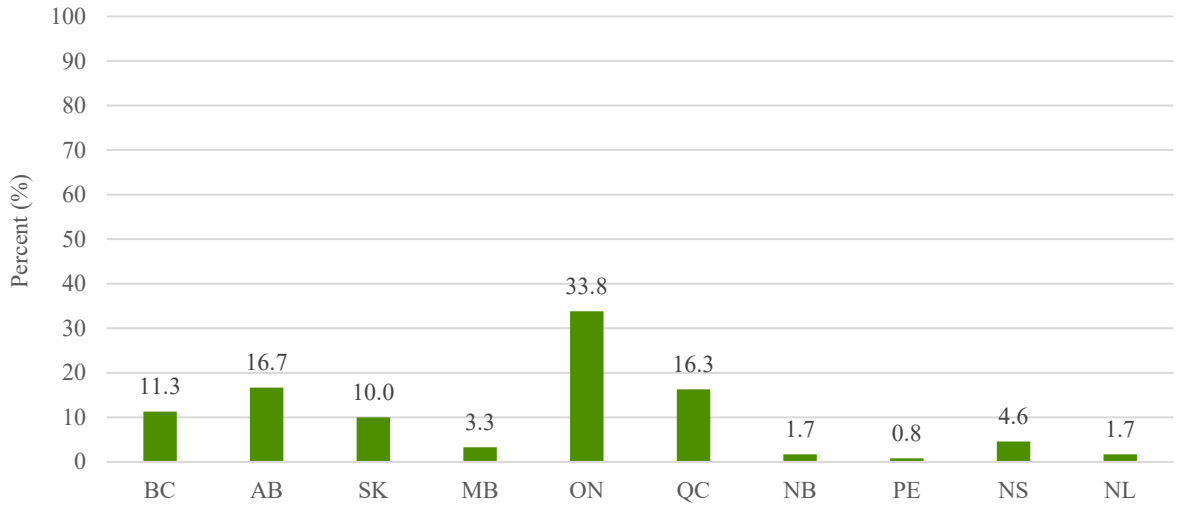
Canadian agriculture technology organizations are located throughout the country **(Figure 1)**, with Ontario accounting for just over one-third (33.8%) of agricultural technology organizations, followed by Alberta (16.7%), and Quebec (16.3%). We also examined the distribution of headquarter locations between urban and rural settings. The majority of agricultural technology organizations (82.9%) have headquarters in Canada's metropolitan regions.

Table 1: Organizational characteristics

Number of Employees	Organizations (#)	Organizations (%)
1 to 10	86	39.6
11 to 50	85	39.2
51 to 100	13	6.0
101 to 250	18	8.3
251 to 500	8	3.7
501 to 1,000	4	1.8
1,000 or higher	3	1.4
Annual Revenue	**Organizations (#)**	**Organizations (%)**
Less than $1 million	19	17.6
$1 million to $9.99 million	65	60.2
$10 million - $49.99 million	18	16.7
$50 million to $99.99 million	4	3.7
$100 million or more	2	1.9
Year Founded	**Organizations (#)**	**Organizations (%)**
Before 1993	33	16.5
1993 to 1997	3	1.5
1998 to 2002	15	7.5
2003 to 2007	12	6.0
2008 to 2012	30	15.0
2013 to 2017	55	27.5
2018 to 2022	52	26.0
Type of Organization	**Organizations (#)**	**Organizations (%)**
For-Profit Business	219	91.6
Research Centre	9	3.8
Non-Profit or Cooperative	7	2.9
Government	4	1.7
Types of For-Profit Business	**Organizations (#)**	**Organizations (%)**
Technology producer	183	83.2
Sales	23	10.5
Consulting services	12	5.5
Implementation services	2	0.9

Source: Crunchbase [Authors' calculations]

Figure 1: Headquarter location by province



Source: Crunchbase [Authors' calculations]

Table 2 shows the distribution of agricultural technology organizations across Census Metropolitan Areas (CMAs). Canada's five largest metropolitan regions account for just over half of the agricultural technology organizations in our study: Toronto (15.1%), Montreal (10.6%), Calgary (9.5%), Vancouver (8.5%), and Edmonton (6.5%).

The remainder of Canada's agricultural technology organizations (17.1%) have headquarters in rural locations distributed across Canada (**Table 3**). However, there are some regional trends. In British Columbia, the majority of rural agricultural technology organizations are located in the Thompson-Okanagan region, known for its cultivation of grapes and tree-fruits. The region is also home to institutions with agriculture education programs including Thompson Rivers University and Okanagan College. Similarly, in Alberta, three of the four rural agricultural technology organizations are located within proximity of Olds College, which offers an undergraduate program in digital agriculture.

In Ontario, most rural agricultural technology organizations are in southwestern Ontario's farming communities. These communities mainly produce field crops, apples, grapes, and tree-fruits. Southwestern Ontario is home to several post-secondary institutions with agriculture education programs, including the University of Guelph, Brock University's Niagara Community Observatory, and Conestoga College.

In Saskatchewan, rural agricultural technology organizations are located throughout the province, but predominantly located in areas where most farms produce a combination of oilseed and beef. Several of these rural Saskatchewan locations are also near the University of Saskatchewan, which offers agriculture educational programs and has a strong reputation for agricultural research. In Quebec, rural agricultural technology organizations are predominantly located in the rural areas between Montreal and Quebec, in proximity to the agriculture education programs at McGill University, Laval University, and L'Institut de technologie agroalimentaire du Québec. It is worth noting that we found no agriculture technology organizations operating in Canada's territories.

Table 2: Headquarter location by Census Metropolitan Area (CMA)

Census Metropolitan Area	Organizations (#)	Organizations (%)
Toronto, ON	30	15.1
Montreal, QC	21	10.6
Calgary, AB	19	9.5
Vancouver, BC	17	8.5
Edmonton, AB	13	6.5
Ottawa-Gatineau, ON	11	5.5
Saskatoon, SK	11	5.5
Quebec City, QC	9	4.5
Halifax, NS	9	4.5
Guelph, ON	8	4.0
Winnipeg, MB	6	3.0
London, ON	5	2.5
Kitchener-Cambridge-Waterloo, ON	5	2.5
St. Catharines-Niagara, ON	4	2.0
Lethbridge, AB	4	2.0
St. John's, NL	3	1.5
Regina, SK	3	1.5
Hamilton, ON	3	1.5
Nanaimo, BC	2	1.0
Fredericton, NB	2	1.0
Brantford, ON	2	1.0
Abbotsford-Mission, BC	2	1.0
Windsor, ON	1	0.5
Victoria, BC	1	0.5
Thunder Bay, ON	1	0.5
Sherbrooke, QC	1	0.5
Moncton, NB	1	0.5
Kingston, ON	1	0.5
Kelowna, BC	1	0.5
Drummondville, QC	1	0.5
Chatham-Kent, ON	1	0.5
Barrie, ON	1	0.5

Source: Crunchbase [Authors' calculations]

Table 3: Headquarter locations in rural areas by province

Province	Rural Area
British Columbia	Campbell River
	Chase
	Clearwater
	Summerland
Alberta	Camrose
	Carstairs
	Irricana
	Lloydminster
Saskatchewan	Beechy
	Kindersley
	Naicam
	Norquay
	Rosetown
	Sedley
	Senlac
	Sherwood
	Swift Current
Manitoba	Arborg
	Morden
	Carman
Ontario	Ayr
	Blenheim
	Exeter
	Lindsey
	Mitchell
	McNab-Braeside
	Norwich
	Tavistock
Quebec	Gaspé
	La Pocatière
	Napierville
	Nicolet
	Normandin
	Saint-Germain-de-Grantham
New Brunswick	Chamcook
Prince Edward Island	Victoria
	North Wiltshire
Nova Scotia	Great Village
	Kentville
Newfoundland	Main Brook

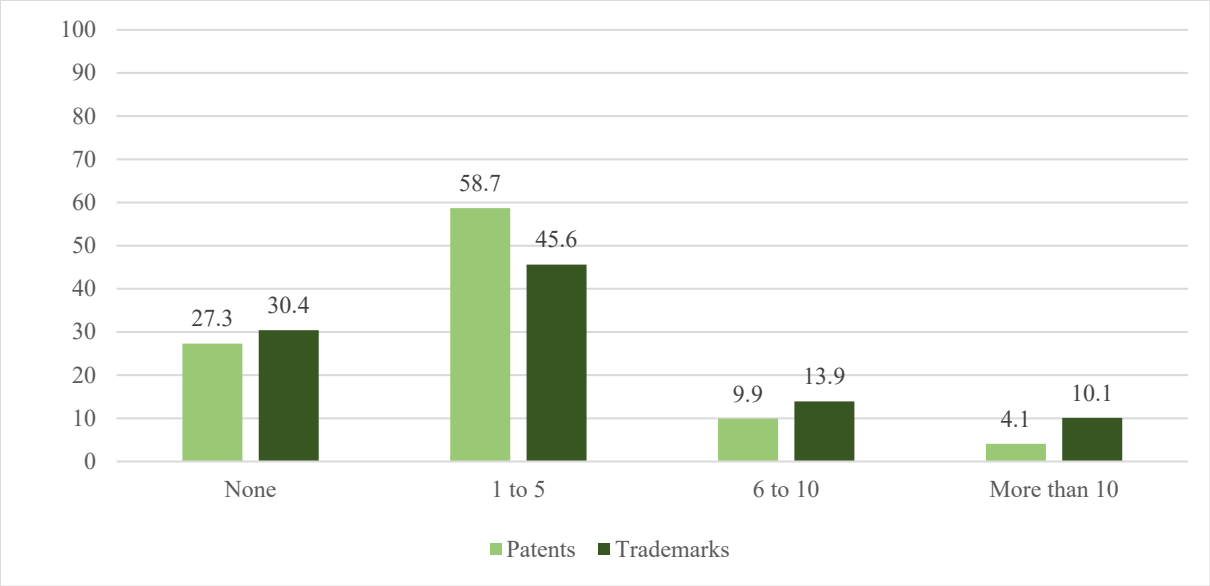
Source: Crunchbase [Authors' calculations]

Overall, location in - or proximity to - major metropolitan centres may offer Canadian agriculture technology firms better access to the skilled labour pools required in the engineering and development of advanced technologies. However, distance from rural farmlands may also create some separation between technology producers and their customers (farms and farmers), making it more difficult to align technology design with the daily work-life realities and hands-on user experiences of farmers.

3.1.3 Intellectual property

Intellectual property indicators can offer insights into the innovation dynamics and capacity of a sector (Hernandez & Galvis, 2021). For this reason, we assessed the number of registered patents and trademarks held by Canadian agriculture technology organizations. While patents and trademarks are a narrow indicator of innovation and do not fully capture innovation capacity, they are one of the most readily available and widely recognized metrics of innovation. **Figure 2** shows that the majority of Canadian agriculture technology organizations have at least one registered patent (72.7%) or one registered trademark (69.6%). A small proportion of organizations have six or more patents (14.0%) or six or more trademarks (24.0%).

Figure 2: Organizations holding intellectual property



Source: Crunchbase [Authors' calculations]

Scholars have noted that Canadian organizations are quite successful in producing early-stage innovations across key sectors, yet many of these organizations face challenges in commercialization and scaling up their business to capitalize on these new products or processes (Gallini & Hollis, 2019). For small and medium enterprises (SMEs) in particular, patent and trademark ownership can indicate the value of their intellectual property, invention or innovation, which can help to secure the investments required for commercialization (Gallini & Hollis, 2019). Given that we find that the majority of Canadian agriculture technology organizations hold intellectual property, the agriculture technology sector may represent an unrecognized source of potential strength and competitiveness. However, sector-specific challenges may limit the further development, commercialization, and adoption of Canadian digital agriculture

technologies. For example, Conteh et al. (2023) identify challenges such as the lack of trust and weak connections between technology providers and the agriculture sector, financial risks associated with innovation and adoption, shifting labour trends, and the length of time required for agriculture innovation and adoption in Canada.

3.1.4 Types of agricultural technology products

Despite the challenges associated with commercializing agricultural technologies, Canadian organizations bring a range of agricultural technology products to market, which we divided into five categories:

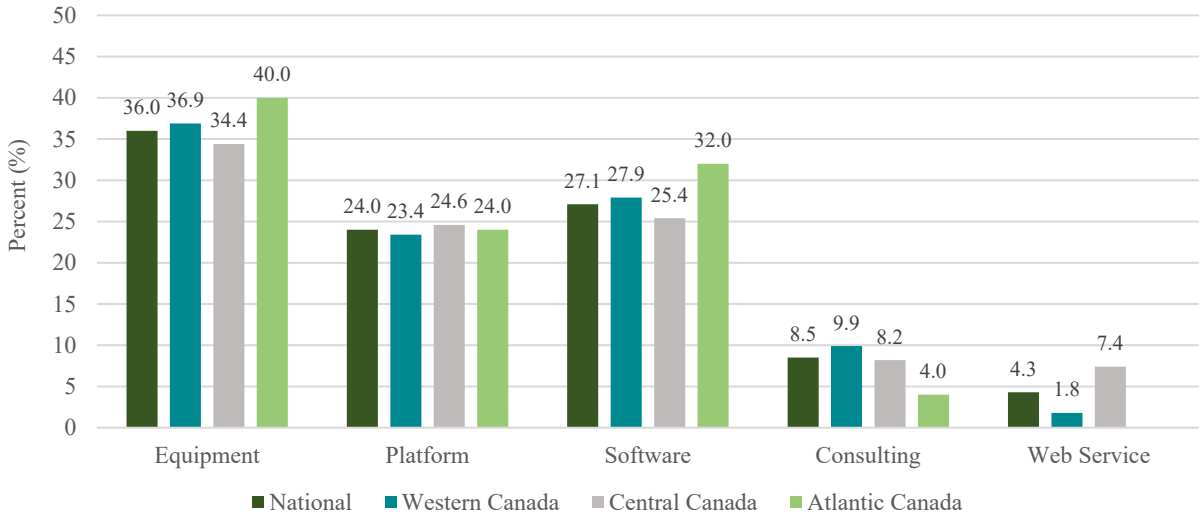
- Equipment-based solutions that involve technology related to heavy machinery and processing equipment;
- Platform-based solutions that include Internet of Things (IoT), sensor systems, and computing;
- Software-based solutions including information management and data processing technologies;
- Consulting services related to planning and implementation of technologies and farm practices; and
- Web services such as information and market intelligence services.

Figure 3 shows that roughly half of Canadian organizations are producing advanced digital agriculture solutions such as software (27.0%) or platform-based (24.0%) solutions. **Figure 3** also shows that equipment-based solutions account for almost another third of organizations (36.0%). Equipment based solutions frequently involve technologies that are incorporated into existing heavy machinery and processing equipment, such as tractors and combines. For example, Canadian farms have been using auto-steering technology for tractors for several decades (Do et al., 2022). Canadian agriculture technology organizations may target this segment of the market because of the lower level of risk involved in farmers adding technology to their existing traditional equipment. These add-on technologies assist farmers in achieving incremental efficiency and productivity gains within their existing farm operations without necessarily requiring substantial changes to their overall operations.

We also examined if there were variations in where different types of agricultural technologies were being produced across Canada. **Figure 3** shows that although organizations specializing in equipment technologies are dominant in every region, there are some regional differences in terms of technology specializations. For example, a slightly higher proportion of organizations in Atlantic Canada focus on equipment technologies and software compared to other regions. In Central Canada, a much higher proportion of organizations focus on web services (7.4%) compared to other regions in Canada. These differences may reflect variations in crops, regional industrial specializations, and the availability of skilled labour. In other words, agricultural technology organizations may orient their product design choices based on the nature of regional agricultural production and the strengths of the regional economy.

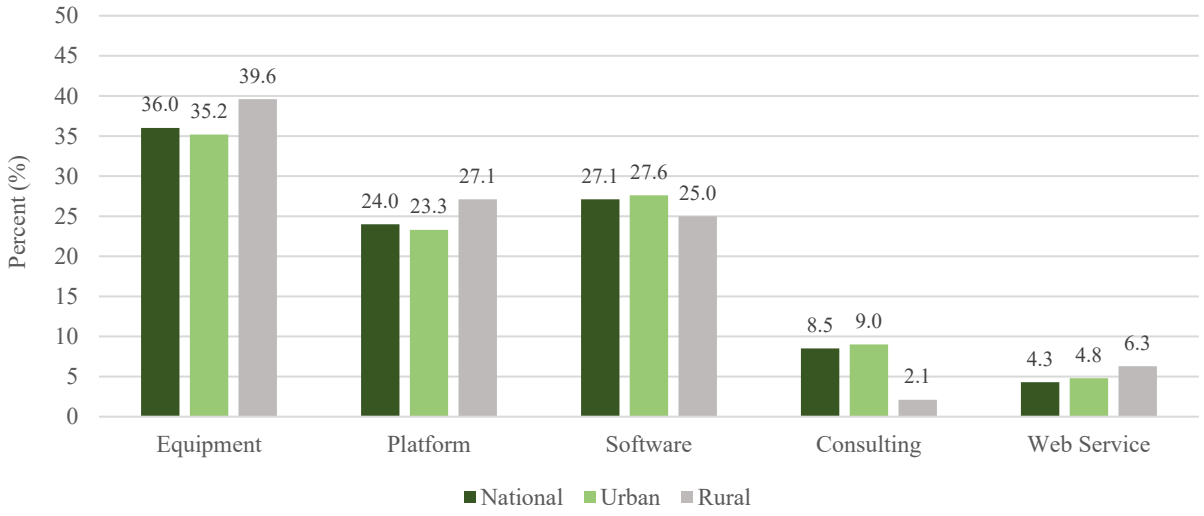
We also observed some differences between urban and rural areas. We found that organizations headquartered in rural areas focus more on equipment, platform technologies and web services compared to their urban counterparts (**Figure 4**). By contrast, there are slightly higher proportions of organizations in urban areas that focus on software or consulting. Organizations specializing in software or consulting may be more likely to benefit from being proximate to other similar firms servicing other industries.

Figure 3: Types of agricultural technology products – Regional differences



Source: Crunchbase [Authors' calculations]

Figure 4: Types of agricultural technology products – Urban vs. rural locations



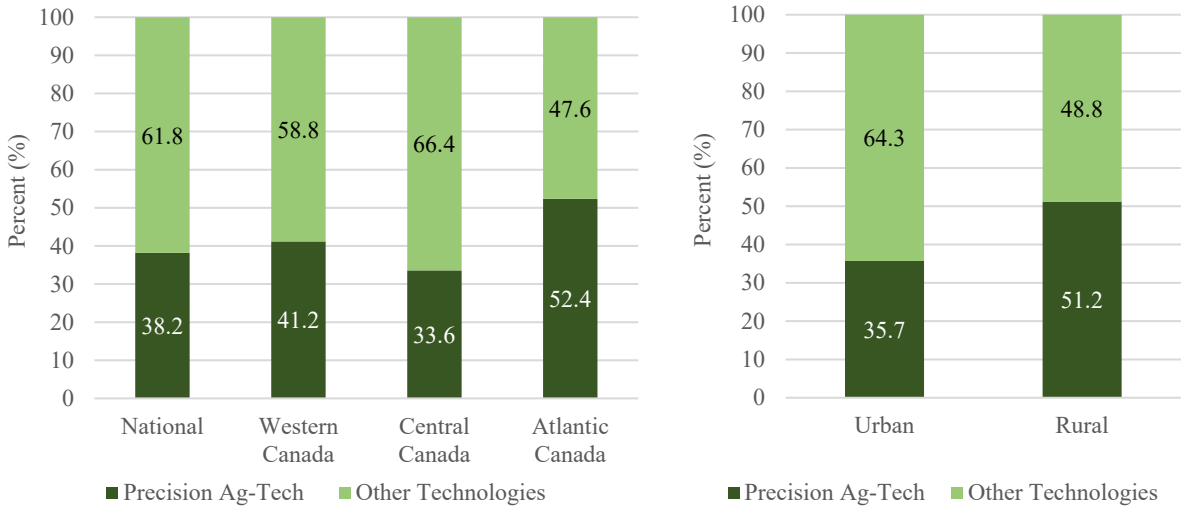
Source: Crunchbase [Authors' calculations]

3.1.5 Precision agriculture technologies

Precision Agriculture (PA) is a set of technologies that support the sustainable intensification of agriculture. PA is also an established marketing term used widely by technology producers. For example, John Deere advertises 'precision ag tools'. Similarly, many other organizations use this term to describe specific products and capabilities including data management, remote management, automation, and variable rate application technologies. We classified whether or not firms were engaged in producing technologies and capabilities that align with common understandings of PA.

Figure 5 compares the proportion of organizations producing PA compared to other agricultural technologies across Canadian regions and between urban and rural areas. Our analysis reveals that there was a higher proportion of organizations in Atlantic Canada (52.4%) and Western Canada (41.2%) compared to Central Canada (33.6%). This is likely because the PA technologies used in Canada are often in-field sensors and system products (that dominate in Western Canada) or livestock management system products (that dominate Atlantic Canada). Moreover, a higher proportion of agricultural technology organizations in rural areas produce PA (51.2%) compared to their urban counterparts (35.7%).

Figure 5: Precision agriculture vs. other technologies by location



Source: Crunchbase [Authors' calculations]

3.1.6 Enabling technologies

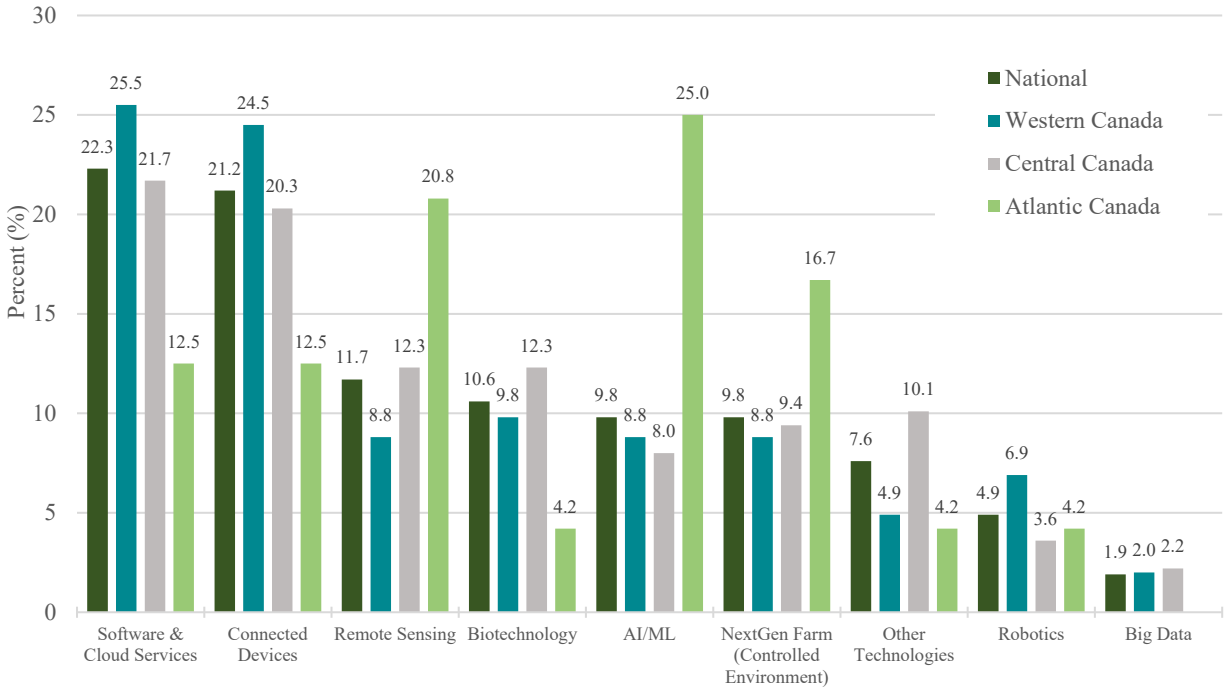
Figure 6 shows the types of supporting or underlying technologies that enable the products and services of Canadian agriculture technology organizations. These include software and cloud-based software services (22.3%), connected devices (21.2%), remote sensing (11.7%), and biotechnology (10.6%). To a lesser degree, agricultural technologies are also enabled by artificial intelligence or machine learning (AI/ML) technologies (9.8%), next-generation (NextGen) farm technologies for indoor controlled environment automation (9.8%), robotics (4.9%), and big data

(1.9%). Notably the proportion of Canadian agricultural technology organizations using AI and robotics technologies in their products is quite low. This stands in contrast to other countries, such as the United States, where the use of AI and robotics technologies is prevalent (Maloku, 2020).

We also examined regional differences in the use of enabling technologies for agricultural technology products. Agricultural technology organizations in Atlantic Canada are more likely to provide products that employ artificial intelligence and robotics (25.0%) or remote sensing (20.8%). It is possible that the greater use of these technologies among Atlantic Canada organizations may be influenced by the proximity to Dalhousie University in Halifax, Nova Scotia, where the Faculty of Agriculture and the Faculty of Engineering run a joint undergraduate program in agricultural engineering that is unique in Canada (Dalhousie University, 2023).

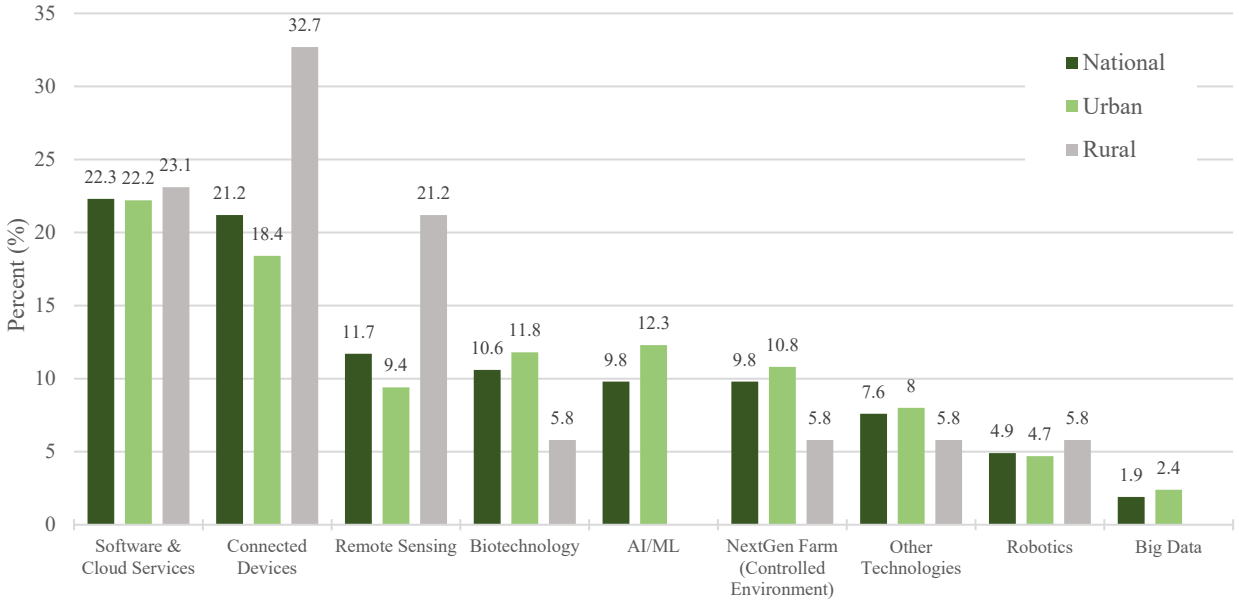
Similarly, we examined differences between urban and rural areas in terms of what types of enabling technologies are being used in developing agricultural technology products (**Figure 7**). Agricultural technology organizations located in rural areas had higher rates of deploying connected device technologies (32.7%) or remote sensing technologies (21.2%).

Figure 6: Enabling technologies – Regional differences



Source: Crunchbase [Authors' calculations]

Figure 7: Enabling technologies – Urban vs. rural locations



Source: Crunchbase [Authors' calculations]

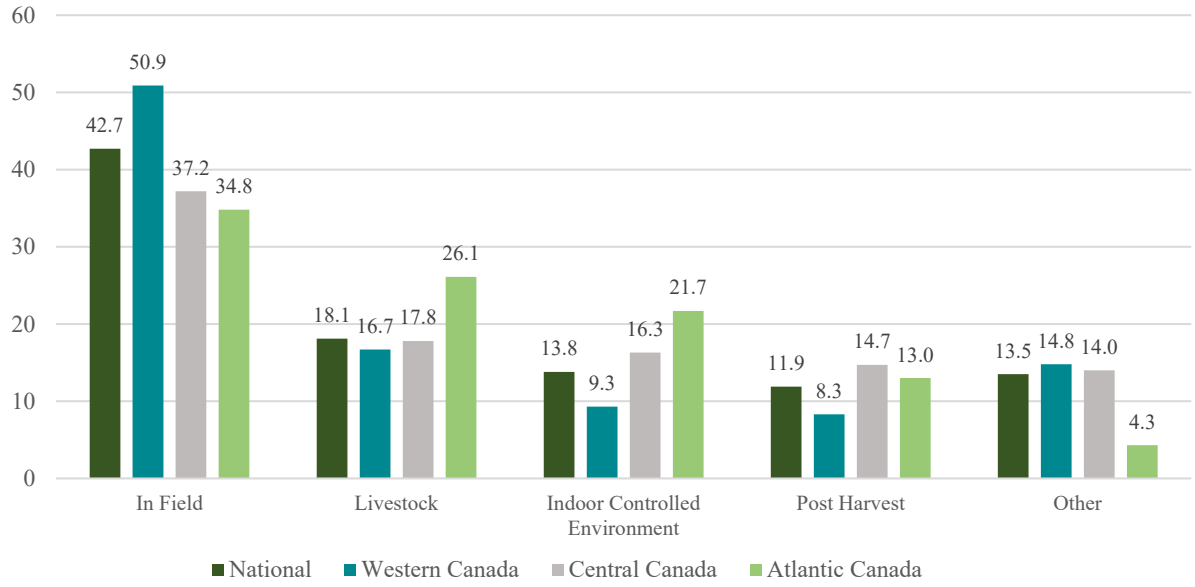
3.1.7 Target application areas

Digital technologies can be applied across a broad range of farm settings and tasks, from planting to harvesting to processing. We identified the specific types of applications targeted by Canadian agriculture technology organizations. Target application areas refer to the intended on-farm settings, workflows, or tasks the product aims to address. Specifically, we identified four target application areas, including:

- In-field settings such as systems and sensors that monitor and track data related to crops, soil, environment, and farm machinery;
- Livestock production such as systems for herd management, health information, automated feeding and milking;
- Indoor or controlled environments such as greenhouses, sunless or vertical growing facilities, and land-based aquaculture; and
- Post-harvest settings that involve processing and tracking agriculture commodities.

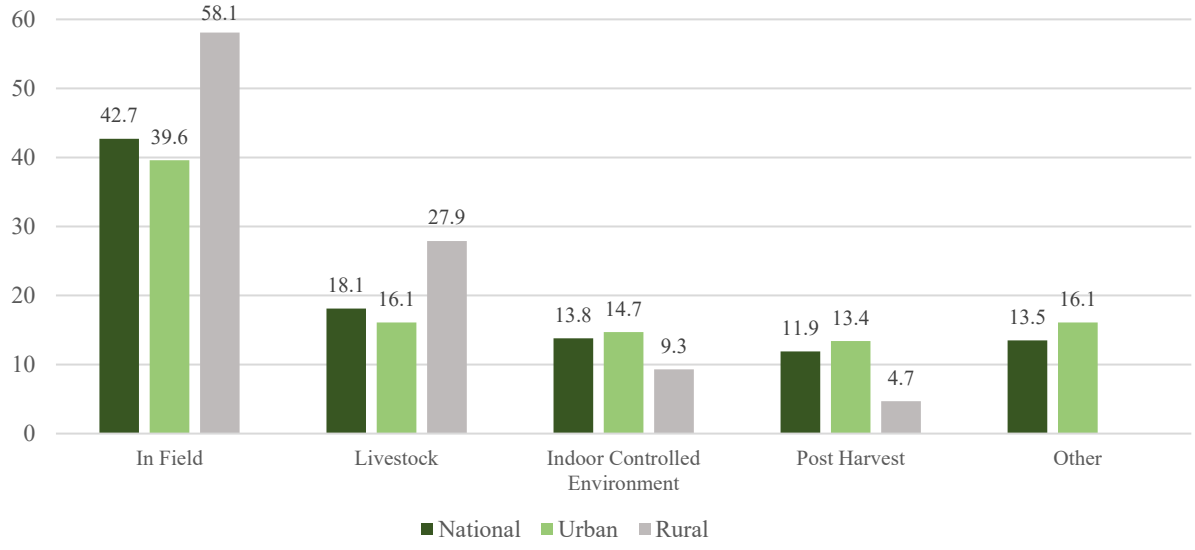
Overall, the most common application area was in-field settings (42.7%) followed by livestock production (18.1%). Again, we examined whether there were variations across different regions of Canada (**Figure 8**) and between urban and rural areas (**Figure 9**). In-field applications were especially predominant in Western Canada (50.9%) and rural locations (58.1%). This is not surprising given the dominance of principal field crop farming in rural areas, especially in the prairies of Western Canada. Western Canada also had the lowest proportion of organizations engaged in applications for indoor controlled environments (9.3%).

Figure 8: Agricultural application – Regional differences



Source: Crunchbase [Authors' calculations]

Figure 9: Agricultural application – Urban vs. rural locations



Source: Crunchbase [Authors' calculations]

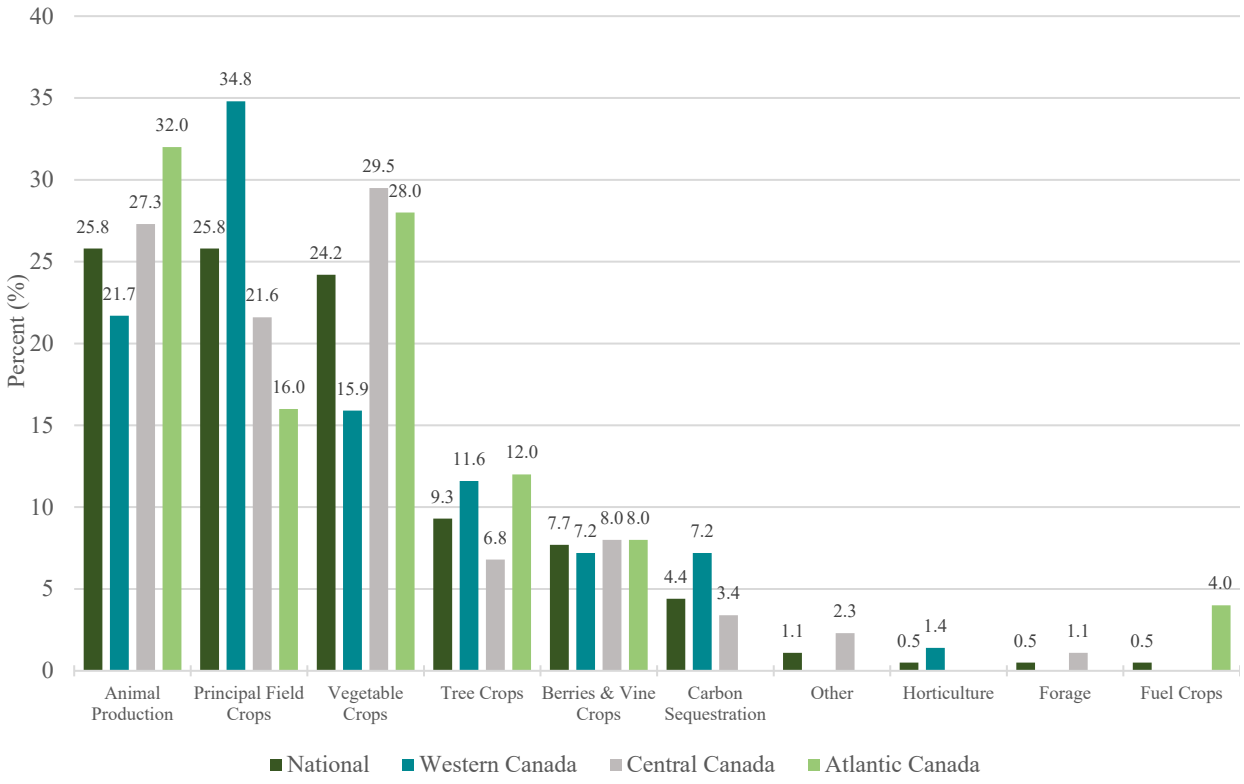
Again, Atlantic Canada stands out as having a substantially different profile compared to other regions in Canada. There is a much higher proportion of organizations that target livestock applications. Indeed, in Atlantic Canada, after in-field applications (34.8%), the next highest target area is livestock applications (26.1%), followed by indoor controlled environments (21.7%), and post-harvest processing (13.0%). Also of note, there were much lower proportions of organizations focused on post-harvest settings in rural communities (4.7%).

3.1.8 Commodities

In addition to broad target application areas, Canadian agriculture technology organizations' products are typically designed for specific types of commodities such as animal production, principal field crops, vegetable crops, tree crops, berries and vine crops, or other specialty crops and commodities. **Figure 10** shows the types of commodities targeted by Canadian agricultural technology organizations by region. Three commodity areas are targeted by the majority of agricultural technology organizations across Canada and its regions: animal production, principal field crops and vegetable crops. However, our findings also reveal regional differences. For example, a much higher proportion of organizations headquartered in Atlantic Canada focus on technologies for animal production (32.0%) compared to other parts of Canada. In Western Canada, just over one-third of organizations focus on principal field crops (34.8%). Meanwhile, organizations in Central Canada are most heavily focused on vegetable crops (29.5%). Again, these differences likely reflect underlying geographic differences in agricultural production across Canada.

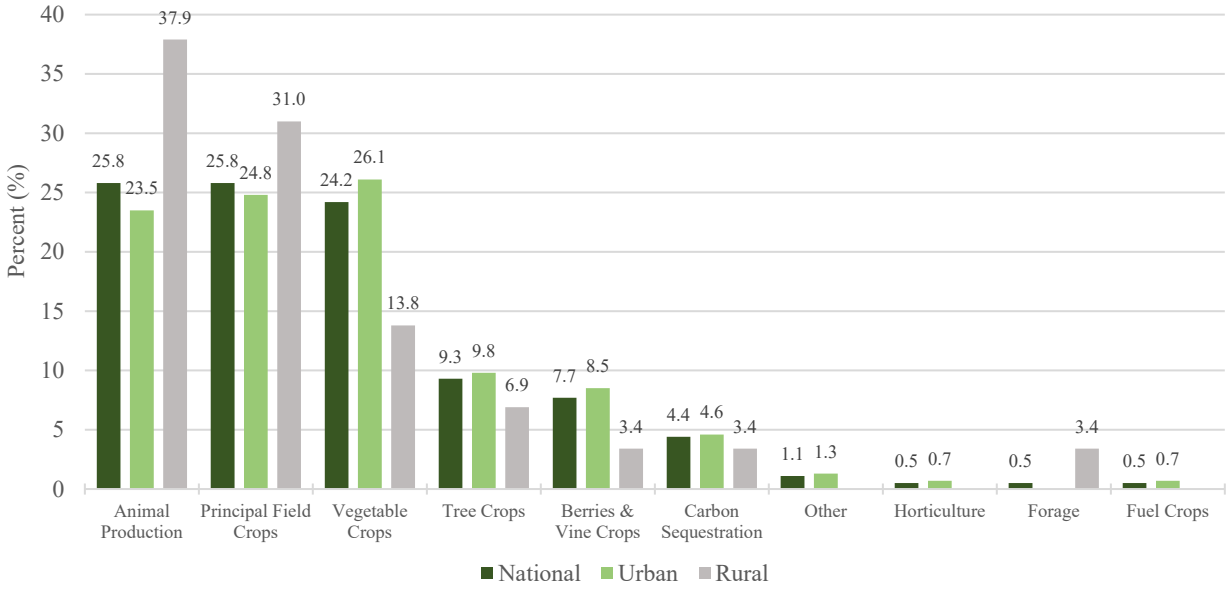
Differences in commodity specialization are more striking when we compare organizations headquartered in urban locations to their rural counterparts (**Figure 11**). Organizations headquartered in rural areas are primarily focused on animal production (37.9%) and principal field crops (31%). While principal field crops (24.8%) and animal production (23.5%) are also among the leading categories in urban locations, there is a greater emphasis on vegetable crops (26.1%), tree crops (9.8%), and berry and vine crops (8.5%) compared to rural areas.

Figure 10: Application by commodity type – Regional differences



Source: Crunchbase [Authors' calculations]

Figure 11: Application by commodity type – Urban vs. rural locations



Source: Crunchbase [Authors' calculations]

3.2 Business, environmental, and social benefits

Given that there is an increasing interest in sustainability in the agricultural sector, we sought to understand the business, environmental and social benefits associated with the digital agricultural technologies produced by Canadian organizations. **Table 4** shows that there is a wide range of business benefits that Canadian agriculture technology organizations identify to their customers and users. The six most common benefits include labour savings (19.7%), enhanced decision making (19.7%), increased output (15.0%), reduced production costs (13.3%), improved quality of commodity products (13.1%) and pest/disease management (10.5%). These benefits were consistently the most cited by agricultural technology organizations across Canada. Similarly, these were the most commonly cited business benefits by organizations headquartered in both urban and rural locations.

The most commonly cited business benefits generally correspond with financial considerations. This is not surprising given that technology organizations must demonstrate to farmers of all types that the sizeable upfront investments to acquire and implement emerging agricultural technologies are worth the financial risk (Do et al., 2022). In contrast, business benefits that have indirect financial implications for customers (farms), such as increased market share, regulatory compliance and enhanced reputation, were highlighted less by Canadian agricultural technology organizations.

We found that Canadian agriculture technology organizations also highlighted a wide range of environmental and social benefits. **Table 5** shows that the most commonly addressed environmental and social benefits include water conservation (11.5%), reduced pesticide use (10.6%), general or non-specific sustainability benefits (10.6%), improved livestock health and safety (10.4%), and reduced fertilizer use (9.5%). Interestingly, most of these benefits address

environmental concerns rather than social issues, such as inequality and food security. Across Canada's regions, there was little variation in terms of the environmental and social benefits emphasized by agricultural technology organizations. There was a slightly greater emphasis on water conservation benefits (13.3%) by organizations headquartered in Western Canada, which may reflect the impacts of draught conditions in Western Canada's agriculture in recent years.

Table 4: Business benefits by location

Business Benefits	National		Western Canada		Central Canada		Atlantic Canada		Urban		Rural	
	#	%	#	%	#	%	#	%	#	%	#	%
Labour Saving	96	19.7	43	20.4	47	19.3	6	18.2	72	18.4	14	16.3
Enhance Decision Making	96	19.7	39	18.5	49	20.2	8	24.2	78	19.9	18	20.9
Increase Output	73	15.0	32	15.2	37	15.2	4	12.1	59	15.1	14	16.3
Reduce Production Costs	65	13.3	34	16.1	29	11.9	2	6.1	50	12.8	15	17.4
Improve Quality	64	13.1	25	11.8	31	12.8	8	24.2	54	13.8	10	11.6
Pest/Disease Management	51	10.5	19	9.0	28	11.5	4	12.1	40	10.2	11	12.8
Increase Market Share	23	4.7	7	3.3	15	6.2	1	3.0	21	5.4	2	2.3
Climate/Frost Management	9	1.8	4	1.9	5	2.1	-	-	8	2.0	1	1.2
Comply with Regulations	5	1.0	4	1.9	1	0.4	-	-	4	1.0	1	1.2
Enhance Reputation	2	0.4	2	0.9	-	-	-	-	2	0.5	-	-
Other	3	0.6	2	0.9	1	0.4	-	-	3	0.8	-	-

Source: Authors' calculations

Table 5: Environmental and social benefits by location

Environmental & Social Benefits	National		Western Canada		Central Canada		Atlantic Canada		Urban		Rural	
	#	%	#	%	#	%	#	%	#	%	#	%
Water conservation	41	11.5	16	13.3	21	10.7	4	9.8	35	11.3	6	12.8
Reduced pesticide use	38	10.6	13	10.8	19	9.7	6	14.6	32	10.3	6	12.8
Improve livestock health & safety	37	10.4	13	10.8	20	10.2	4	9.8	29	9.4	8	17.0
Reduced fertilizer use	34	9.5	12	10.0	16	8.2	6	14.6	28	9.0	6	12.8
Improved soil health	24	6.7	9	7.5	14	7.1	1	2.4	21	6.8	3	6.4
Reduced waste	23	6.4	7	5.8	15	7.7	1	2.4	20	6.5	3	6.4
Agricultural intensification	21	5.9	8	6.7	9	4.6	4	9.8	19	6.1	2	4.3
Energy reduction	20	5.6	6	5.0	12	6.1	2	4.9	17	5.5	3	6.4
Improve consumer safety	17	4.8	4	3.3	13	6.6	-	-	16	5.2	1	2.1
Food security	16	4.5	3	2.5	7	3.6	6	14.6	15	4.8	1	2.1
Reduced food miles	15	4.2	5	4.2	9	4.6	1	2.4	14	4.5	1	2.1
Improve employee safety	13	3.6	6	5.0	7	3.6	-	-	12	3.9	1	2.1
Reduced GHG emissions	9	3.6	4	5.0	5	3.6	-	-	7	2.3	2	4.3
Reduced inequalities	6	1.7	-	-	5	2.6	1	2.4	5	1.6	1	2.1
Reduced erosion	5	1.4	2	1.7	3	1.5	-	-	5	1.6	-	-
Other/Non-specific	38	10.6	12	10.0	21	10.7	5	12.2	35	11.3	3	6.4

Source: Authors' calculations

Table 5 also shows that there were some minor differences between organizations headquartered in urban and rural areas. Benefits related to water conservation (12.8%), reduced pesticide use (12.8%), improved livestock health and safety (17.0%) and reduced fertilizer use (12.8%) were emphasized more by organizations with headquarters in rural areas than by their urban counterparts.

3.2.1 Business, environmental and social benefits by target application area

Table 6 and **Table 7** shows the extent to which agricultural technology organizations emphasize particular business and environmental and social benefits based on the types of target application areas the organization was focused on. **Table 6** shows that regardless of target application area, organizations emphasized labour savings and increased output. Enhanced decision making was emphasized by organizations across all application areas, except for indoor and controlled environment agriculture. Reduced production costs were more greatly emphasized by all organizations, except those engaged in post-harvest applications. Improved quality was also highlighted to by all organizations, but to a lesser degree amongst organizations developing in-field applications. Organizations developing in-field technologies also highlighted pest/disease management (14.1%) and organizations focused on post-harvest technologies were also more likely to highlight increased market share (13.3%).

Table 7 shows that there was greater variability with respect to which environmental and social benefits organizations emphasized. For example, organizations focused on in-field applications were more likely to emphasize environmental and social benefits related to reduced pesticide use (18.6%), reduced fertilizer use (15.5%), water conservation (12.4%), improved soil health (12.4%) and other sustainability benefits (13.2%). By comparison, organizations focused on post-harvest technologies were more likely to address environmental and social benefits related to improved consumer safety (28.0%), reduced waste (16.0%), and improved livestock health and safety (16.0%). Organizations focused on livestock, not surprisingly emphasized improved livestock health and safety (38.4%) and water conservation (12.8%). Finally, organizations focused on indoor or controlled environment technologies highlighted reduced food miles (14.3%), agricultural intensification (13.3%), and water conservation (12.2%)

Table 6: Business benefits by target application area

Business benefits	In-field		Post-harvest		Livestock		Indoor/controlled environment	
	#	%	#	%	#	%	#	%
Labour Saving	57	21.1	8	13.3	15	20.5	14	23.0
Enhance Decision Making	65	24.1	14	23.3	12	16.4	2	3.3
Increase Output	37	13.7	7	11.7	11	15.1	8	13.1
Reduce Production Costs	39	14.4	4	6.7	10	13.7	17	27.9
Improve Quality	27	10	16	26.7	13	17.8	12	19.7
Pest/Disease Management	38	14.1	1	1.7	7	9.6	2	3.3
Increase Market Share	3	1.1	8	13.3	2	2.7	3	4.9
Climate/Frost Management	3	1.1	-	-	-	-	2	3.3
Comply with Regulations	-	-	1	1.7	2	2.7	-	-
Enhance Reputation	-	-	1	1.7	1	1.4	-	-
Other	1	0.4	-	-	-	-	1	1.6

Source: Authors' calculations

Table 7: Environmental and social benefits by target application area

Environmental and social benefits	In-field		Post-harvest		Livestock		Indoor/controlled environment	
	#	%	#	%	#	%	#	%
Water Conservation	16	12.4	1	4.0	11	12.8	12	12.2
Reduced Pesticide Use	24	18.6	1	4.0	3	3.5	8	8.2
Reduced Fertilizer Use	20	15.5	1	4.0	2	2.3	7	7.1
Improved Soil Health	16	12.4	-	-	1	1.2	1	1.0
Reduced Waste	3	2.3	4	16.0	8	9.3	7	7.1
Ag Intensification	6	4.7	-	-	3	3.5	13	13.3
Energy Reduction	5	3.9	1	4.0	5	5.8	11	11.2
Improve Livestock Health & Safety	4	3.1	4	16.0	33	38.4	2	2.0
Improve Consumer Safety	4	3.1	7	28.0	5	5.8	2	2.0
Improve Employee Safety	4	3.1	1	4.0	3	3.5	-	-
Food Security	3	2.3	2	8.0	2	2.3	8	8.2
Reduced Food Miles	-	-	-	-	1	1.2	14	14.3
GHG Emissions Reduction	3	2.3	-	-	1	1.2	6	6.1
Reduced Inequalities	1	0.8	1	4	1	1.2	3	3.1
Reduced Erosion	3	2.3	-	-	-	-	-	-
Sustainability - Other/Non-specific	17	13.2	2	8.0	7	8.1	4	4.1

Source: Authors' calculations

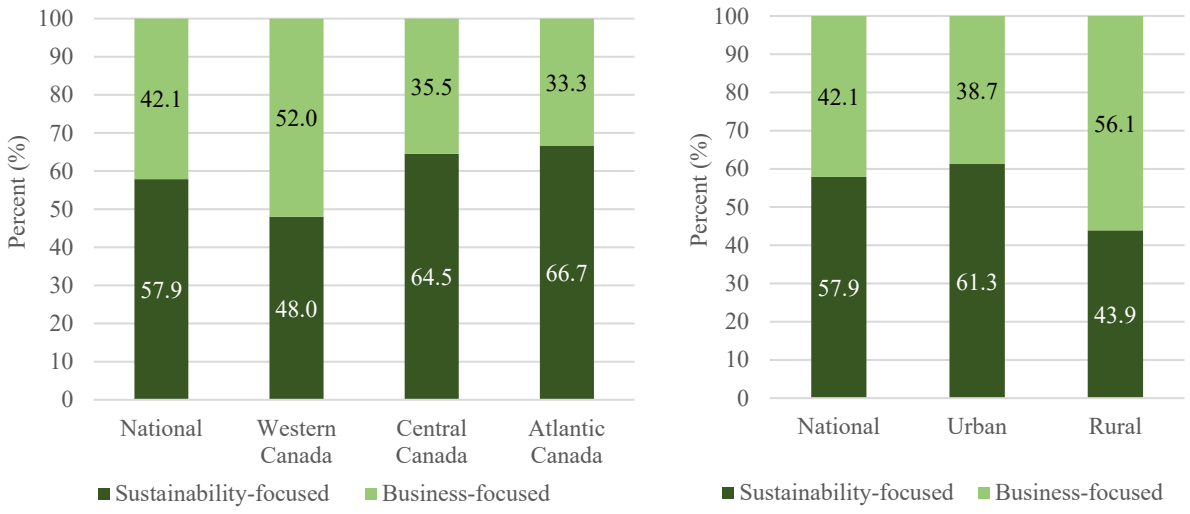
3.2.2 Sustainability vs. business focus by location

Despite increasing awareness and discussion of sustainable agriculture practices in Canada, environmental and social factors are not being emphasized by agricultural technology producers. It is plausible that agricultural technology producers assume that this is less important to their customers or that their customers might associate environmentally and socially focused technologies with adding more uncertainty to an already risk-intensive business (Do et al., 2022).

We found that Canadian agriculture technology organizations generally position the environmental and social benefits of their products as distinct and separate from business benefits, rather than as synergistic or complementary advantages. Indeed, while all organizations communicated the business benefits of their technologies, we found that less than two-thirds of Canadian agriculture technology organizations (57.9%) also mentioned environmental and social benefits (**Figure 12**). Thus, in the remainder of our analysis we distinguish between organizations that emphasize business, environmental and social benefits (*sustainability-focused*) compared to those that only highlight business benefits (*business-focused*).

Figure 12 also shows geographic differences in the extent to which agricultural technology organizations emphasize environmental and social benefits. Less than half of agricultural technology organizations in Western Canada (48.0%) emphasized environmental and social benefits, whereas almost two-thirds of organizations in Central Canada (64.5%) and Atlantic Canada (66.7%) emphasized environmental and social benefits. Differences also exist between organizations headquartered in urban and rural locations. Among organizations headquartered in urban areas, 61.3% communicated environmental or social benefits, compared to only 43.9% of organizations headquartered in rural areas (**Figure 12**), suggesting that agricultural technology organizations located in urban centres are more likely to be sustainability focused.

Figure 12: Sustainability vs. business focus by location



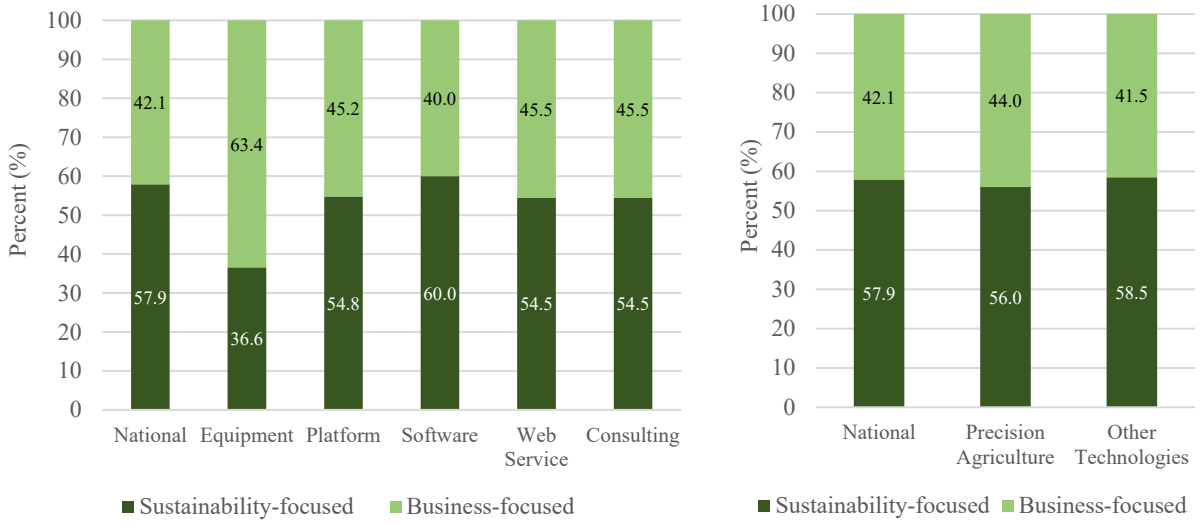
Source: Authors' calculations

3.2.3 Sustainability vs. business focus by type of technology product

We also examined if there were differences in the propensity to highlight environmental and social benefits by the type of technology product and between organizations producing precisions agriculture (PA) technologies versus other technologies. **Figure 13** shows that fewer organizations focused on equipment-based technologies (36.6%) emphasized environmental or social benefits. However, almost two-thirds of software-based technologies (60.0%) focused on environmental and social benefits, more than organizations in other technology product categories.

We also found that there were minimal differences in the propensity to emphasize environmental and social benefits between organizations producing precision agriculture (PA) technologies (56.0%) versus other technologies (58.5%). We focused on PA given the potential for PA technologies to support sustainable intensification of agriculture. However, almost half of Canadian organizations producing PA technologies focused only on business benefits (44.0%) and made no mention of environmental or social benefits and there were no clear differences between organizations focused on PA technologies compared to other technologies. It is possible that due to the high costs related to adopting and implementing PA technologies, organizations producing these technologies in Canada emphasize the business benefits to address cost barriers and highlight the financial return on investment by their customers.

Figure 13: Sustainability vs. business-focus by technology product type



Source: Authors' calculations

3.3 Sustainability, innovation and the gender diversity of leadership teams

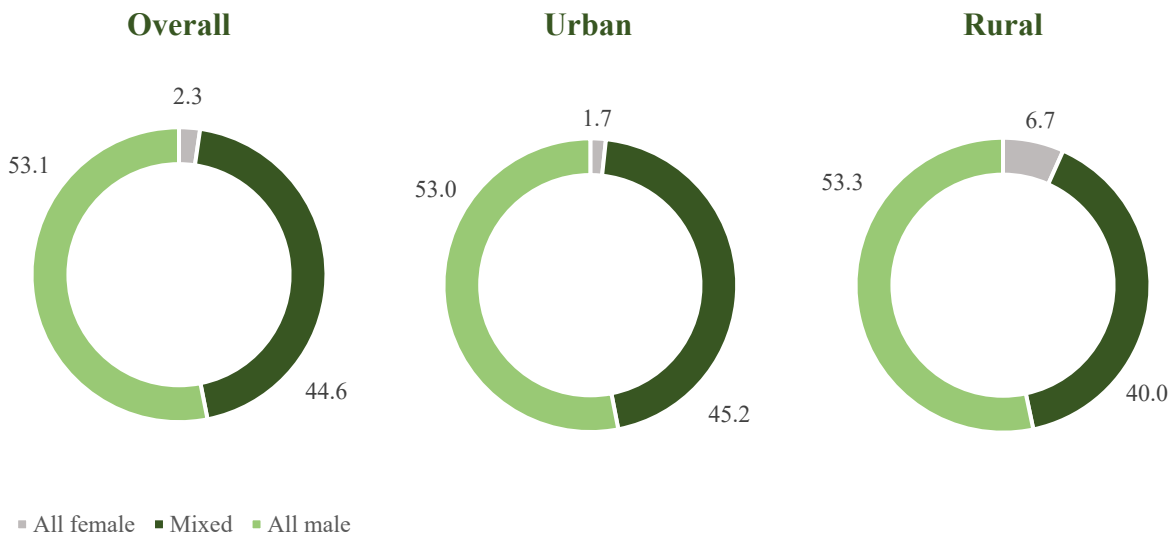
Studies show that firms with leadership and management teams that embody gender diversity experience improved economic performance, innovation outcomes, and greater competitive advantages (Ferrary & Déo, 2022). Over the last decade, Canadian businesses have increased the gender diversity of their leadership teams, which has led to the increased representation of women in senior positions (Devillard et al., 2021). Although the global COVID-19 pandemic slowed advances related to the gender diversity of leadership and management teams among Canadian firms, industries such as retail trade, utilities, and finance and insurance have achieved high levels of gender diversity in terms of the composition of their leadership teams (The Prosperity Project, 2023). However, recent data from Statistics Canada indicates that the agricultural industry itself has substantially lower numbers of women in senior leadership and management roles compared to other industries (Statistics Canada, 2023b). Moreover, high tech industries have historically faced challenges in promoting and including women and other disadvantaged groups (White, 2024). Thus, the agricultural technology industry sits at the nexus of two industries that have historically faced challenges related to diversity in their management and leadership teams. A lack of diversity in the management and leadership in Canada's agriculture technology sector may impede innovation, economic performance and competitiveness for organizations in the sector, as well as the sector overall.

We explored the leadership teams of Canadian agricultural technology organizations to understand the extent to which these organizations have embraced gender diversity in their leadership. We further explored if there is a relationship between gender diversity in senior leadership and innovation, as well as an emphasis on wider sustainability benefits (rather than business-only benefits) associated with the organization's digital agricultural technologies.

Among the organizations included in our study, slightly more than half (130 or 52.6%) reported details about their leadership teams. Leadership teams ranged in size from four to twelve members. Among those organizations that reported their leadership team membership, just over half (53.1%) had exclusively male teams (**Figure 14**). The remainder of these organizations had either mixed-gender teams (44.6%) or all-female teams (2.3%).

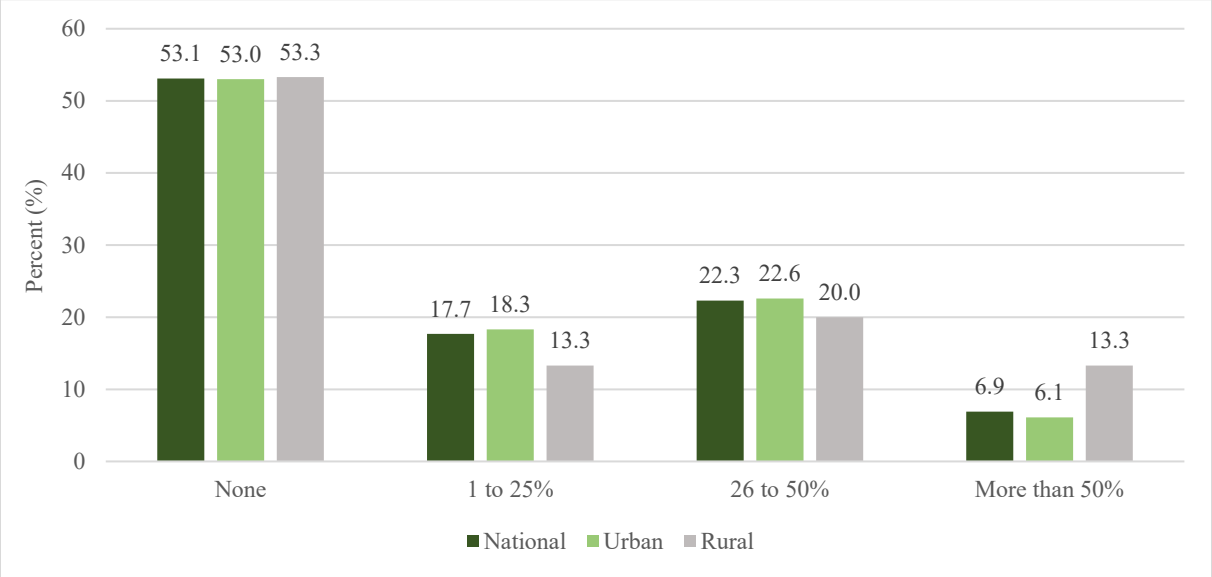
We also observed few differences between organizations headquartered in urban and rural areas. There are roughly the same proportion of all-male leadership teams, however there was a higher proportion of organizations in rural areas with teams comprised entirely of women (6.7%) compared to organizations headquartered in urban areas (1.7%) (**Figure 14**). This is also reflected in **Figure 15**, which shows that 13.3% of agricultural technology organizations headquartered in rural areas had leadership teams where more than half of the team was female. While rural-based organizations had higher proportions of women in senior positions, the overall pattern suggests that there remain low levels of gender diversity across leadership teams in agriculture technology organizations, which mirrors traditional sectors in Canada (The Prosperity Project, 2023; Statistics Canada, 2023b).

Figure 14: Gender diversity of leadership teams by location



Source: Authors' calculations

Figure 15: Proportion of women in leadership roles – Urban vs. rural locations

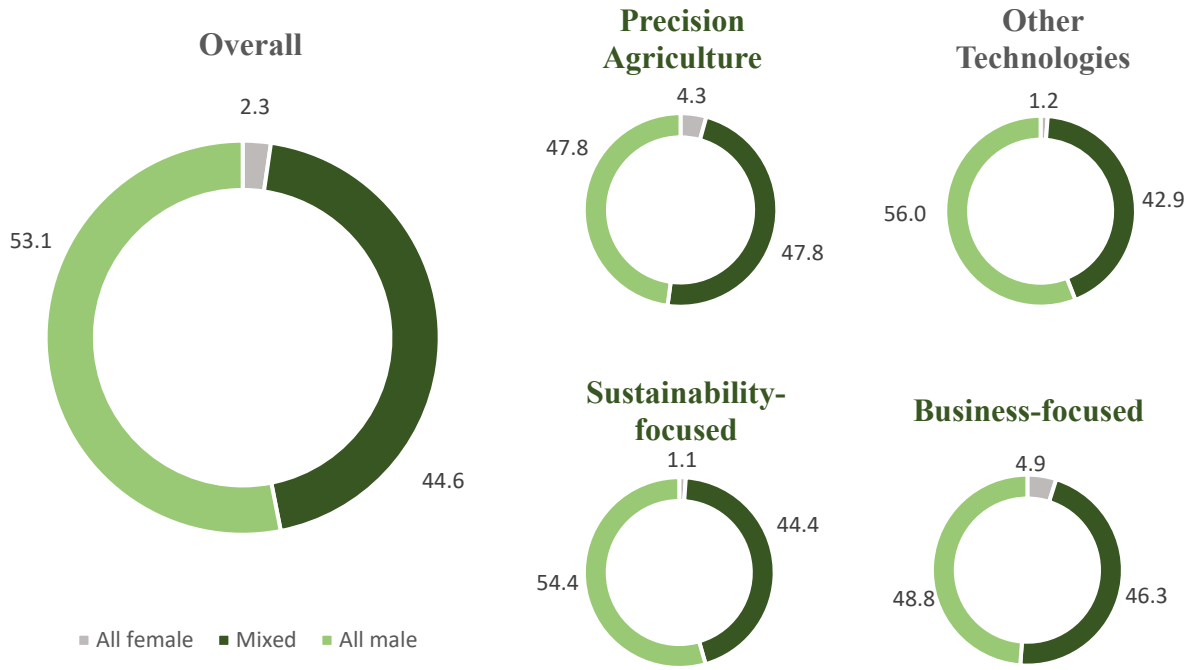


Source: Authors' calculations

We also explored whether gender diversity on leadership teams led to either a focus on the sustainability benefits (rather than a business-only focus) of products and services, or stronger innovation outcomes. **Figure 16** shows the distribution of organizations based on the gender diversity of their leadership teams, and then compares organizations focused on precision agriculture versus other technologies, as well as organizations that highlighted broader sustainability benefits compared to organizations that only highlighted business benefits. There were fewer male-only leadership teams in precision agriculture (47.8%) than organizations focused on other technologies (56.0%), although these are relatively small differences. Overall, there were few differences based on whether an organization promoted broader sustainability benefits rather than only business benefits.

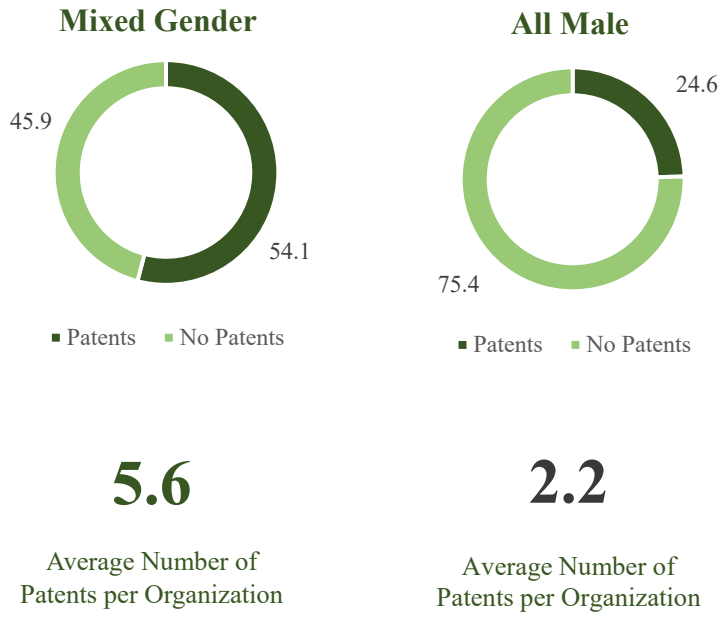
However, when examining patents as a proxy for innovation, we found a slightly different story. We found that agricultural technology organizations with women in leadership roles were far more likely to own at least one patent (54.1%), compared to leadership teams with men only (24.6%) (**Figure 17**). Moreover, among agricultural technology organizations that own patents, those organizations with gender diverse leadership teams also owned more than double the number of patents on average (5.6 patents) compared to those agricultural technology organizations with exclusively male leadership teams (2.2 patents).

Figure 16: Technology focus, sustainability and the gender diversity of leadership teams



Source: Authors' calculations

Figure 17: Patent ownership and the gender diversity of leadership teams



Source: Crunchbase [Authors' calculations]

4 Summary and conclusions

The purpose of this report was to examine agricultural technology firms in Canada, the location and characteristics of these firms, and to determine if the technologies developed by these firms are positioned as enabling business, environmental, and social benefits. More specifically we sought to answer the following key questions using a novel dataset of 247 agricultural technology organizations:

1. What are the characteristics of Canadian agricultural technology organizations?
2. What business, environmental, and social benefits do Canadian agricultural technology organizations emphasize?
3. Is there a relationship between the gender diversity of leadership teams, innovation outcomes, and a focus on sustainability?

4.1 Characteristics of Canadian agricultural technology organizations

With regards to the characteristics of Canadian agricultural technology organizations, most of the agricultural technology organization in our analysis were small to medium sized businesses with fewer than 50 employees and more than two-thirds of agricultural technology organization have annual revenues of less than $10 million (CAD). In addition, more than half of Canadian agriculture technology organizations were founded in the last ten years. As noted earlier, smaller

and younger firms may be better positioned to respond to evolving market conditions and more readily able to meet specific customer needs. However, these organizations may also be challenged to invest in longer-term R&D or compete against large, established firms.

When examining the geography of agricultural technology organizations, over four-fifths of agricultural technology organizations in our analysis were headquartered in Canada's metropolitan areas. Being located in – or in proximity to - major metropolitan centres may offer Canadian agriculture technology firms better access to skilled labour. However, distance from rural farmlands may also create some separation between technology producers and their customers (farms and farmers), making it more difficult to align technology design with the daily work-life realities and hands-on user experiences of farmers.

Interestingly, over two-thirds of the agricultural technology organizations in our analysis hold registered patents and registered trademarks, which signals that the agriculture technology sector may represent an unrecognized source of potential strength and competitiveness in Canada.

The majority of Canadian agricultural technology organizations in our analysis were engaged in creating equipment, platform and software-based solutions, and used a range of enabling technologies including software and cloud-based software services, connected devices, remote sensing, biotechnology, artificial intelligence or machine learning (AI/ML) technologies, and next-generation (NextGen) farm technologies for indoor controlled environment automation. In addition, in-field applications were most common overall, but organizations were also involved in creating technology solutions for livestock and indoor controlled environment systems. Finally, the majority of Canadian agriculture technology organizations were designed for a specific commodity, with animals, principal crops, and vegetable crops each accounting for roughly one-quarter of the organizations included in our analysis.

4.2 Business, environmental, and social benefits

Overall, we found a wide range of business, environmental and social benefits that Canadian agriculture technology organizations in our analysis identified to their customers and users. With regards to business benefits, labour savings, enhanced decision making, increased output, reduced production costs, improved quality of commodity products, and pest/disease management were most commonly cited. With respect to environmental and social benefits, most of top-cited benefits address environmental concerns rather than social issues, including water conservation, reduced pesticide use, general or non-specific sustainability benefits, improved livestock health and safety, and reduced fertilizer use.

Interestingly, we found that the Canadian agriculture technology organizations included in our analysis generally position the environmental and social benefits of their products as distinct and separate from business benefits, rather than as synergistic or complementary advantages. In fact, while all organizations communicated the business benefits of their technologies, we found that less than two-thirds of Canadian agriculture technology organizations also mentioned environmental and social benefits.

We also found that less than half of agricultural technology organizations in Western Canada emphasized business, environmental and social benefits, whereas almost two-thirds of organizations in Central and Atlantic Canada emphasized sustainability benefits rather than business-only benefits. Differences also existed between organizations headquartered in urban and rural locations, with almost two-thirds of organizations headquartered in urban areas being sustainability-focused compared to less than half of organizations headquartered in rural areas, suggesting that agricultural technology organizations located in urban centres are more likely to be sustainability-focused.

4.3 Sustainability, innovation and the gender diversity of leadership teams

Our analysis shows that slightly more than half of Canadian agricultural technology organizations have exclusively male leadership teams. Interestingly, there was a higher proportion of organizations in rural areas with leadership teams comprised entirely of women compared to organizations headquartered in urban areas. Rural-based organizations also had higher proportions of women in leadership roles. Nonetheless, there remain low levels of gender diversity across leadership teams in agriculture technology organizations, which mirrors traditional sectors in Canada.

We further explored if there is a relationship between gender diversity in senior leadership and innovation, as well as an emphasis on wider sustainability benefits (rather than business-only benefits) associated with the organization's digital agricultural technologies. Overall, we observed limited differences based on whether an organization promoted broader sustainability benefits rather than only business benefits based on the gender composition of their leadership team. However, when examining patents as a proxy for innovation, we found that agricultural technology organizations with women in leadership roles were more than twice as more likely to own at least one patent. Moreover, among agricultural technology organizations that own patents, those organizations with gender diverse leadership teams also owned more than double the number of patents on average compared to those agricultural technology organizations with exclusively male leadership teams.

4.4 Looking ahead: Opportunities for future research

Overall, our research provides novel insights into the state of Canada's agricultural technology sector. Several observations stand out. First, there are substantive variations across Canada's vast geography and between urban and rural areas. Many of these regional variations reflect underlying local industrial structures and agricultural specializations. They may also reflect variations in the policy environment and the quality of local institutions, including college and university programs and research capacity. These patterns can only be understood through further careful, in-depth research and study. Given that the majority of Canada's agricultural technology producers are located within urban regions, there are opportunities to further understand the locational decisions of these firms, especially given that many of their customers would be located outside of urban boundaries. And, it may be that these firms are entering global markets, rather than focusing on Canadian customers. There remain open questions about how locational

choices and market orientation might impact the development and adoption of innovative agricultural technologies that are appropriate for use in Canada's agricultural sector.

Second, we note the relatively low proportion of Canadian agricultural technology organizations using AI and robotics technologies in their products, especially in comparison to competitor nations. Given the growing interest in AI and robotics across industries, this may be an area of policy concern, with downstream implications for the competitiveness and productivity of the agricultural sector writ large.

Third, we observe that business benefits were emphasized much more than sustainability benefits, which stands in contrast to the growing interest in sustainability across the agricultural sector. Moreover, there were some differences between organizations focused broadly on sustainability compared to those that were more business-focused. Again, this merits further analysis to better understand how sustainability considerations are integrated (or not) in the sector.

Finally, we note that – similar to many traditional sectors in Canada – the leadership teams of agricultural technology organizations did not reflect gender diversity. However, while we found limited relationships between the gender diversity of leadership teams and a focus on sustainability, we did find higher levels of innovation (measured by patents) among organizations with gender diverse leadership teams. These findings require further investigation to understand if there are ways to further bolster innovation in the broader agricultural sector.

5 References

AIC (2017). An Overview of the Canadian Agricultural Innovation System. Ottawa, ON: Agricultural Institute of Canada.

Basso, B., & Antle, J. (2020). Digital agriculture to design sustainable agricultural systems. *Nature Sustainability, 3*(4), 254-256. DOI: 10.1038/s41893-020-0510-0

Bronson, K. (2018). Smart farming: including rights holders for responsible agricultural innovation. *Technology Innovation Management Review, 8*(2), 7–14.

Bhakta, I., Phadikar, S., & Majumder, K. (2019). State-of-the-art technologies in precision agriculture: a systematic review. *Journal of the Science of Food and Agriculture. 2019;99*(11):4878-4888. DOI:10.1002/jsfa.9693

Conteh, C., Lemay, M., & Boggs, J. (2023). Building Competitive Agri-Food Production Systems. Brock University, Niagara Community Observatory. Retrieved on November 13, 2023: https://brocku.ca/niagara-community-observatory/wp-content/uploads/sites/117/NCO-Agri-Innovation-Final-Report-01.2023-FINAL.pdf

Crunchbase (2023). Where does Crunchbase get their data? Retrieved on September 7, 2023: https://support.crunchbase.com/hc/en-us/articles/360009616013-Where-does-Crunchbase-get-their-data

Dalle, J., Den Besten, M., & Menon, C. (2017). Using Crunchbase for economic and managerial research. *OECD Science, Technology and Industry Working Papers*, 2017/08. DOI: 10.1787/18151965

Dalhousie University (2023). Faculty of Environment: Departments. Retrieved on November 13, 2023: https://www.dal.ca/faculty/agriculture/departments.html

Dalle, J., M. den Besten and C. Menon (2017). Using Crunchbase for economic and managerial research, *OECD Science, Technology and Industry Working Papers*, No. 2017/08, OECD Publishing, Paris, https://doi.org/10.1787/6c418d60-en.

Devillard, S., Bonin, G., Bergeron, N., Pan, T., and Zucker, L. (2021). Gender diversity at work in Canada. McKinsey Company and LeanIn.Org. Retrieved on November 13, 2023: https://www.mckinsey.com/ca/~/media/mckinsey/locations/north%20america/canada/gender%20diversity%20at%20work/gender_diversity_at_work_in_canada.pdf

Do, T., Powell, N., Stackhouse, J., Guldimann, C., Richardson, B., Huq, F., Chow, D., Khanm, Z., Smith-Edgell, A., Wu, K., Paddock, G., Bouw, B., Halliday, K., Fletcher, C., Hoo, S., Backler, W., Aroub, Y., Pedrinelli, P, Sharma, R., Fraser, R., Mugabe, D., Pulido-Castanon, J., Sharma, R. (2022). The Transformative Seven: Technologies that can drive Canada's next green revolution. *RBC Climate Action Institute*. Retrieved on November 13, 2023: https://thoughtleadership.rbc.com/the-transformative-seven-technologies-that-can-drive-canadas-next-green-revolution/

Ferrary, M., & Déo, S. (2023) Gender diversity and firm performance: when diversity at middle management and staff levels matter. *The International Journal of Human Resource Management, 34*:14, 2797-2831, DOI: 10.1080/09585192.2022.2093121

Fielke, S., Bronson, K., Carolan, M., Eastwood, C., Higgins, V., Jakku, E., ... & Wolf, S. A. (2022). A call to expand disciplinary boundaries so that social scientific imagination and practice are central to quests for 'responsible' digital agri-food innovation. *Sociologia Ruralis, 62*(2), 151-161. DOI: 10.1111/soru.12376

Gallini, N., & Hollis, A. (2019). To Sell or Scale Up: Canada's Patent Strategy in a Knowledge Economy. IRPP Study, August 2019. Retrieved on November 13, 2023: http://irpp.org/wp-content/uploads/2019/08/To-Sell-Or-Scale-Up-Canadas-Patent-Strategy-in-a-Knowledge-Economy.pdf

Government of Canada (2022). Overview of Canada's agriculture and agri-food sector. Retrieved on November 13, 2023: https://agriculture.canada.ca/en/sector/overview

Government of Canada (2023). AgriInnovate Program. Retrieved on November 13, 2023: https://agriculture.canada.ca/en/programs/agriinnovate

Garavito Hernandez, Y., & Rueda Galvis, J. F. (2021). Innovation and patents as a business success factor. *Journal of Economics, Finance and Administrative Science, 26*(51), 143-159.

Invest in Canada (2023). Agri-Tech: Where Innovation Grows. Retrieved on November 13, 2023: https://www.investcanada.ca/industries/agri-tech

Jasanoff, S. (2015). Future imperfect: science, technology, and the imaginations of modernity. In: Jasanoff, S. & Kim, S.-H. (Eds.) *Dreamscapes of modernity: sociotechnical imaginaries and the fabrication of power*, 1–26. Chicago, IL: University of Chicago Press.

Makinde, A., Islam, M., Wood, K., Conlin, E., Williams, M., & Scott, S. (2022). Investigating perceptions, adoption, and use of digital technologies in the Canadian beef industry. *Computers and Electronics in Agriculture*, *198*, 107095. DOI: 10.1016/j.compag.2022.107095

Maloku, D. (2020). Adoption of precision farming technologies: USA and EU situation. *SEA–Practical Application of Science, 8*(22), 7-14.

Mitchell, S., Weersink, A, & Bannon, N. (2020). Adoption barriers for precision agriculture technologies in Canadian crop production. *Canadian Journal of Plant Science, 2020;101*(3):412-416. DOI:10.1139/cjps-2020-0234

Monteiro, A., Santos, S., and Gonçalves, P. (2021). Precision Agriculture for Crop and Livestock Farming—Brief Review. *Animals (Basel). 2021;11(8)*:2345-. DOI:10.3390/ani11082345

Nelles, J., Walsh, K., Papazoglou, M., Nyanzu, E., Abdul, S., Vorley, T. (2023). Place Based Innovation in the UK: Case Studies. *Innovation Caucus, Oxford Brookes University*.

Retrieved on September 7, 2023: https://innovationcaucus.co.uk/app/uploads/2023/06/Clusters-Part-2_Case-Studies-FINAL-22-June-2023.pdf

OECD (2013). Agricultural Innovation Systems: A Framework for Analysing the Role of the Government. *Paris: OECD Publishing*.

Plastina, A. and T. Townsend. 2023. "World Spending on Agricultural Research and Development." Agricultural Policy Review, Winter 2023. Center for Agricultural and Rural Development, Iowa State University. Retrieved on November 27, 2023: www.card.iastate.edu/ag_policy_review/article/?a=152

Sharif, A., Saqib, N., Dong, K., & Khan, S. A. R. (2022). Nexus between green technology innovation, green financing, and CO2 emissions in the G7 countries: The moderating role of social globalisation. *Sustainable Development.* DOI: 10.1002/sd.2360

Spigel, B. and Vinodrai, T. (2021). Meeting its Waterloo? Recycling in entrepreneurial ecosystems after anchor firm collapse. *Entrepreneurship and Regional Development*. 33:7-8: 599-620. https://doi.org/10.1080/08985626.2020.1734262

Statistics Canada (2023a). Gross domestic expenditures on research and development, 2020 (final), 2021 (preliminary), and 2022 (intentions). Retrieved on November 13, 2023: https://www150.statcan.gc.ca/n1/daily-quotidien/230127/dq230127b-eng.htm

Statistics Canada (2023b). Representation of women on boards of directors and in officer positions, 2020. Retrieved on June 20, 2024: (https://www150.statcan.gc.ca/n1/daily-quotidien/230529/t002b-eng.htm

Steele, D., 2017. *Analysis of Precision Agriculture Adoption & Barriers in Western Canada, Final Report*. Agriculture and Agri-Food Canada, Guelph, ON, Canada. Retrieved on September 7, 2023: https://static.agcanada.com/wp-content/uploads/sites/3/2017/05/Final-Report-Analysis-of-Precision-Agriculture-Adoption-and-Barriers-in-western-Canada-April-2017.pdf

The Prosperity Project (2023). The Zero Report: The Prosperity Project 2023 Annual Report Card on Gender Diversity and Leadership. Retrieved on November 13, 2023: https://canadianprosperityproject.ca/data-tracking

United Nations (2023). Goal 2, Zero Hunger. Retrieved on September 7, 2023: https://www.un.org/sustainabledevelopment/hunger/

Vantage Market Research (2022). *Digital Agriculture Market - Global Industry Assessment & Forecast*. Retrieved on September 7, 2023: https://www.vantagemarketresearch.com/industry-report/digital-agriculture-market-1751

White, S.K. (2024). Women in tech statistics: The hard truths of an uphill battle. Retrieved on June 26, 2024: https://www.cio.com/article/201905/women-in-tech-statistics-the-hard-truths-of-an-uphill-battle.html

Yaghi, M., Powell, N., Panahov, F., Freestone, C., Chow, D., Talukder, S., Paddock, G., Aroub, Y., Halliday, K., Fletcher, C., Foucault, T., Unnikrishnan, S., Hoo, S., Pedrinelli, P., Fraser, E., Mohammed, I., Mugabe, D., and Ashton, L. (2023a). Farmers Wanted: The labour renewal Canada needs to build the Next Green Revolution. *RBC Climate Action Institute*. Retrieved on November 13, 2023: https://thoughtleadership.rbc.com/farmers-wanted-the-labour-renewal-canada-needs-to-build-the-next-green-revolution/

Yaghi, M., Hussain, Y., Powell, N., Chow, D., Tlukder, S., Biasoni, C., Truong-Regan, M., Paddock, G., Fraser, E., Mohammed, I., Ashton, L., Duncan, E., Berz, K, Halliday, K., Hoo, S., Fletcher, C., Foucault, T., Whitehouse, T., and Kornas, C. (2023b). A Neg Ag Deal: A 9-Point Plan for Climate-Smart Agriculture. *RBC Climate Action Institute*. Retrieved on November 13, 2023: https://thoughtleadership.rbc.com/a-new-ag-deal-a-9-point-plan-for-climate-smart-agriculture/

Yu, Peter K (2023). Intellectual Property, Foreign Investment and Sustainable Development. *The Elgar Companion to Intellectual Property and Sustainable Development Goals*, Bita Amani, Caroline B. Ncube and Matthew Rimmer, eds., Edward Elgar Publishing, pp. 534-55, 2023, Texas A&M University School of Law Legal Studies Research Paper No. 23-48, Available at SSRN: https://ssrn.com/abstract=4447741