

Precision Agriculture Technologies for Nutrient Management in British Columbia

Clean Technology Scoping Study

FINAL REPORT

Prepared for:

British Columbia Ministry of Agriculture

March 1, 2019

Bioenterprise Corporation

Jaral Corporate Centre
120 Research Lane, Suite 200
Guelph, ON N1G 0B4

The Delphi Group

428 Gilmour St.
Ottawa, ON K2P 0R8

Acknowledgements

The Delphi Group and Bioenterprise Corporation would like to thank the following government agencies and organizations. These key stakeholders provided important resources, insights and/or data to support this study.

AGCO Corporation

AgDNA

Blackbird Environmental

British Columbia Ministry of Agriculture

Climate Corporation

Decisive Farming

Echelon Ag (Nutrien Ag, Crop Production Services)

GroPoint

iDUS Controls

Ontario Ministry of Agriculture, Food and Rural Affairs

Ontario Agri-Food Technologies

SoilOptix

Teralytic

Trident Processes

BIOENTERPRISE
Building Ag-Bio Based Businesses

DELPHI GROUP

Executive Summary

The British Columbia (BC) Ministry of Agriculture is interested in identifying clean technology options that align with provincial priorities; have positive impacts on climate, air, land, and water; and are feasible for implementation in BC. Precision agriculture technologies for nutrient management planning are of particular interest to the BC Ministry of Agriculture as nutrient loading is a prominent issue in parts of the province. Nutrient management planning is a growing activity for farms throughout the province and the BC Government is assessing technologies that are available to assist farmers in this planning, as well as for long-term, on-farm nutrient management and productivity improvements.

The Delphi Group, in partnership with Bioenterprise Corporation, conducted an agriculture clean technology scoping study on behalf of the BC Ministry of Agriculture to identify and assess precision agriculture technologies for nutrient management that are specifically relevant and applicable in BC. The project included defining the technologies, developing a data collection framework, undertaking scoping research (including a targeted literature review and a series of 14 key informant interviews), and synthesizing the results presented into this report.

Overview of Precision Agriculture Technology in North America

Precision agriculture for nutrient management is a farming practice that uses data gathering technologies (e.g., proximal and remote sensors), analytics, and precision application controls to guide farm management practices related to nutrient application. "Nutrients" can include synthetic chemicals, naturally occurring compounds, and animal and plant waste. Use of precision agriculture for nutrient management has the potential to improve nutrient use efficiency, as well as farm productivity.

For the purposes of this study, precision agriculture for nutrient management has been categorized into three main processes, and further sub-divided into six main groups of technologies.

Process	Definition	Technology Groups
Nutrient Monitoring	Technologies that use global positioning systems (GPS) or geographic information systems (GIS) and a variety of sensors (e.g., optical, electrochemical, mechanical, moisture, airflow, temperature, etc.) to capture data pertaining to soil and crop attributes.	Geo-location and Geo-imagery (GPS/GIS)
		Sensors
Nutrient Planning	Technologies (hardware and software) that use raw data gathered from the nutrient monitoring technologies for a precise mapping of a field to be used in nutrient planning and application.	Geo-location/Geo-imagery Processing
		Application Programming Interface (API) and Data Analytics
Nutrient Application	Technologies capable of applying nutrients (e.g., nitrogen, phosphorus) and soil ameliorants (e.g., lime) in a site-specific manner based on accumulated data recommendations for each sampling point.	Variable Rate Technologies (VRT)
		Guidance and Autosteer

It is rare that one of these technologies would be used on its own in precision agriculture, as each depends on or feeds into another. For example, prescription maps can be developed through a combination of GPS/GIS technologies and processing, on farm or aerial sensors, and data analytics. Prescription maps are then fed into variable rate technologies (VRT) for the application of farm inputs, such as fertilizers.

Industry Trends

The global precision agriculture technology market has seen steady growth over the last decade, with improved products on the market and higher adoption rates. According to a 2017 study by Stratistics MRC, the global market accounted for $2.81 billion USD (approximately $3.65 billion CAD)[1] in 2014, and is expected to increase to $6.43 billion USD (approximately $8.36 billion CAD) by 2022, at a compound annual growth rate (CAGR) of 12.5%.[2] A 2018 study by BIS Research estimated that the market would reach $10.55 billion USD (approximately $13.71 billion CAD) by 2025, at a CAGR of 13.7%.[3] The key driving forces for the global precision agricultural market include increasing global sales potential; growing demand for food; eminence of wireless, telematics, and “big data” solutions; government interventions; concerns on energy and cost efficiencies; and consumer pressure for more transparency on farming practices (e.g., where their food is coming from, the health of the soil, how environmentally responsible the farmers are, etc.). Compared to cost savings, increasing crop yields and reducing environmental impacts will play a growing role in the future for driving precision agriculture technology adoption.

Overview of the BC Farm Sector

The number of farms has been decreasing in BC, down 11.3% since 2011, which is nearly double (5.9%) the decline nationally. Total farm area has declined by 0.8% and land in crops has declined 3.1%. The distribution (number) of farms across BC is presented in the table below.

Primary Agricultural Regions	Small Farms (under 400 acres)	Medium farms (400 to 2880 acres)	Large Farms (2880 acres and over)
Vancouver Island - Coast Region: Includes CARs 17, 19, 21, 26	1725	16	1
Lower Mainland - Southwest Region: Includes CARs 9, 15	3891	46	3
Thompson - Okanagan Region: Includes CARs 7, 33, 35, 37, 39	4580	264	95
Cariboo Region: Includes CARs 14, 53	545	316	97
Peace River Region: Includes CARs 55, 59	440	469	146

More than 40% of BC farms are considered small farms; however, farms are generally increasing in size and therefore the impact of individual farms on the environment is also increasing. BC’s ideal growing conditions allow farmers to grow over 200 different commodities. Of the total farmland in 2016, 62% was in pasture land (e.g., tame or seeded pasture and natural land for pasture); 23% was is in crops (e.g., hay and field crops, fruits, field vegetables, and sod and nursery products); 14% was used for farmland, and the remaining 1% was summer fallow. Within BC, all reported crops, excluding tame hay and wheat, are increasing in both average yield and total production. Statistics Canada estimated that the population of BC surpassed five million in 2018.[4] Between 2007 and 2017, the population grew by 12.3%.[5] Increasing population results in increasing demand on production of food crops, particularly under the stresses of

[1] Conversion assumes 1 USD = 1.3 CAD.
[2] Lamb, J. (2017). *Precision Farming Market Size, Share, Report, Analysis, Trends & Forecast to 2022*. Reuters. Retrieved from https://www.reuters.com/brandfeatures/venture-capital/article?id=14966.
[3] BIS Research. (2018). Global Precision Agriculture Market Anticipated to Reach $10.55 billion by 2025, BIS Research Report. Cision PR Newswire. Retrieved from https://www.prnewswire.com/news-releases/global-precision-agriculture-market-anticipated-to-reach-10-55-billion-by-2025-bis-research-report-899815577.html
[4] Statistics Canada. (2018). Canada’s population estimates, third quarter 2018. Retrieved from https://www150.statcan.gc.ca/n1/daily-quotidien/181220/dq181220c-eng.htm
[5] Statistics Canada. Population. Retrieved from https://www150.statcan.gc.ca/n1/pub/12-581-x/2018000/pop-eng.htm

climate change, which also impacts availability of imported food (e.g., due extreme weather events in California, Mexico, and other jurisdictions). Precision agriculture technologies can be used in BC to improve productivity and yields of food crops, while also lowering operational costs.

Opportunities for Precision Agriculture Technologies in Nutrient Management in BC

Precision agriculture technologies have the potential to address some of the major challenges faced by the agricultural industry in BC, including nutrient loading in areas where there are high concentrations of livestock, poultry and eggs, grain crops, and horticultural production. The management of nutrients on-farm can involve many different practices including, but not limited to, composting, tillage practices, residue management, use of cover crops and green manure crops, manure management, crop rotation, fertilizer application, pest management, irrigation, grazing management, and GPS and field mapping. These practices can be complex and require a significant amount of information and data; however, the integration of precision agriculture technologies on-farm can simplify and optimize nutrient management planning.

There are a number of variables to consider when assessing opportunities for precision agriculture technologies in BC for nutrient management. Farm size, crop type, landscape, and weather conditions can all impact the potential for precision agriculture technologies. As a result, there will be regional differences in terms of what technology will be the most beneficial, both profit-wise and environmentally, and this may even differ from farm-to-farm within the same region. The following table provides a high-level overview of the opportunities for precision agriculture technologies in BC. Additional details are provided in the technology group profiles below.

Process	Technology Groups	High-Level Relevance to BC
Nutrient Monitoring	Geo-location and Geo-imagery (GPS/GIS)	Monitoring (e.g., nutrient soil sensors) may be the most important component of precision agriculture for nutrient management on any farm, as it provides the groundwork to help determine where the variation in nutrients can be found and where opportunities exist to better manage nutrients.
	Sensors	
Nutrient Planning	Geo-location/Geo-imagery Processing	Analytics is an up-and-coming practice in the agricultural sector on “big data” processing and may not be suitable to every type of farm. However, its application is most promising in areas that have confined agricultural production (e.g., Fraser Valley, Okanagan Valley) where high value crops and operations rely on high nutrient application, water, and intense management.
	Application Programming Interface (API) and Data Analytics	
Nutrient Application	Variable Rate Technologies (VRT)	VRT and autosteer technologies are most applicable to areas of high acreage production and GPS/GIS coverage. VRT is especially useful in annual crop production and high acreage row crops (e.g., grain and oilseed crops in particular). Further use in inconsistent soil conditions will elevate the effectiveness of VRT.
	Guidance and Autosteer	

Taking a “systems” approach to precision agriculture would help to integrate all relevant technologies (e.g., monitoring, planning, and application) to capture localized micro environmental data, as well as macro level information. However, there are challenges, not the least of which are initial capital costs and a current lack of interoperability between technologies and technology groups (see below). Instead, a collection of techniques and technologies to collect, analyze, and use data are selected based on overall farm profile, which are different for each location, crops, terrain, and soil type. Nevertheless, use of some precision agriculture technologies on BC farms can lead to enhanced profitability with favourable environmental impacts.

Technology Group Profiles

Technology Group	Costs & ROI	Technology Risks & Readiness	Commercial Status	Relevance to BC
Geo-location and Geo-imagery (GPS/GIS)	o The costs for satellite data are low per hectare, but the total cost is high because commercial providers require a minimum area for coverage. o The initial cost may be high for a single task, but the same unmanned aerial vehicle (UAV) can often be used for multiple tasks. o Cost range: $10/acre for raw image files to $57/acre for a normalized difference vegetation index (NDVI) image. o Cost range for remote sensing from manned aircraft: $1/acre to $3/acre. o One example of ROI was between $20 and $75/acre. o Increases the operational efficiency of production.	o Nutrient deficiencies are difficult to detect with satellite imagery. o Satellite-based remote sensing for precision agriculture is still limited by coarse spatial resolution, cloud interference during image acquisition, and slow turn-around times. o Systems/technologies are data intensive. Data generating/ collecting/managing/analyzing is expensive.	o GPS and GIS technologies, satellite imagery, now much more accessible and less cost prohibitive. o Use of GPS devices lead to mapping of fields allowing farmers to use site-specific and precise solutions for their nutrient management issues. o UAV-based remote sensing applications for various agriculture applications has soared over the last decade.	o Satellite imaging and high-altitude drone technologies would likely have good application in large scale farming operation areas like the Peace River District and Williams Lake. o Near ground or on-ground equipment or in-ground technologies may be more applicable to smaller or hilly farms.
Sensors	o The cost of sensors has been declining as manufacturing processes have improved and technologies developed. o Enhanced NPK soil sensors considered to be in line with conventional soil moisture sensors (e.g., $650/probe per year + one-time installation cost of $1,800). o One source (Reuters) indicated a low ROI in the sensor industry of 4.88%. o Return on sensors will likely be as a result of the use of variable rate technologies for nutrient applications in conjunction with the sensors. Sensor provide the data required to optimize resources on-farm.	o Communication of sensors with the central controller, without any interference and at low power consumption, can be a challenge. o Optical sensors are limited in effectiveness for nutrient deficiency monitoring. o Some sensors are limited by environmental tolerance. o The type of data that is being collected has transitioned from gathering simple numerical values (e.g., yield, water quality) to include more qualitative information (e.g., odour) at high accuracy.	o The amount of data collected on farms through sensors has increased dramatically over the last decade. o Declining cost of sensor technologies has allowed farmers to monitor factors such as soil health, soil moisture, etc. in almost real time conditions. o Some technologies (e.g., wireless sensors) are at the early commercialization stage. o Sensors are typically simple and easy to use and therefore may be adopted more readily than other technology types.	o Sensor technology packages are decreasing in size and price and are being made available to smaller farm operations. o On-equipment technologies may be useful in high plateau areas. o The installation and calibration of equipment before use generally requires technical expertise, which may or may not be available in certain regions of the province.
Geo-location/Geo-	o CAPEX is minimal (e.g., cell phone, computer, tablet or other viewing tool).	o Technology risk lays within the method of data gathering. For	o Sophistication of the technology is increasing relatively quickly.	o The higher costs of this technology make it relatively

Technology Group	Costs & ROI	Technology Risks & Readiness	Commercial Status	Relevance to BC
imagery Processing (Geo-analytics)	○ OPEX for a traditional user would include paying a subscription or licensing fee to use the data processing/analytics platform. ○ Annual cost of a typical full geospatial analytical service (e.g., imagery analysis, prescriptions, scouting) is $13,000 per farm or less. For smaller farms, the cost is typically around $5/acre, capped at $10,000. ○ Reduces average input and increases crop yield for high production areas. ○ Reduces average input with similar yield for low production areas.	example, a minimum number of 'passes' may be required by a satellite or UAV to feed the analytics systems. The time between passes is one of the largest risks to this type of prescription. ○ Analytics platforms have existed for several decades through government organizations. However, in the past 10 years, private organizations have launched constellation satellites allowing the option of private prescriptions for the general market.	○ Growing competitiveness in the agricultural geospatial analytics sector due to the increasing number of start-up and analytics platforms licensing raw data from existing satellite constellations.	inaccessible to smaller farms. ○ Satellite imaging and high-altitude drone technologies/analytics would likely have good application in large scale farming operation areas such as the Peace River District and Williams Lake. ○ Lower altitude drone technologies/analytics would have use in the Okanagan and Fraser Valleys where farm size is smaller, but land is highly productive and subject to significant management.
Application Programming Interface (API) and Data Analytics	○ The cost for growers is typically the cost of web-based annual subscription fees, which vary depending on the product and level of service. For example, a service that includes API, data collection, composite soil sampling, and flat rate prescriptions may cost approximately $3.50/acre. Whereas, a service that includes API, data collection, zone-based soil sampling, and variable rate prescriptions may cost approximately $6/acre. ○ In addition, hardware may be required for some companies to collect and upload data. ○ ROI is generally accepted to be positive. One independent study against typical growers resulted in an ROI of approximately $15/acre.	○ To date, full service companies tend to own the farm data and do not make the raw data available to the farmers, which means that the farmer cannot use this data with other technology applications. ○ Specific to data analytics around nitrogen management, changing how nitrogen is used on farms is a big risk, as it is critical to crop yield. Without scientific, independent data, this is not a decision that will be taken easily by most growers. ○ Without local expertise and support (e.g., at the dealer level), deploying APIs and data analytics tools can be more of a challenge.	○ Use of APIs in the agriculture industry is relatively new, though have quickly become commonplace. ○ Big data analytics companies have focused their efforts and tools for US application (particularly for predictive analytics). ○ Commercially available, but newly emerging with little “real world” testing resulting in lower application/comfort levels to date.	○ Provided technology availability and local support, the use of data analytics is particularly relevant to those areas that have confined agricultural production (e.g., Fraser Valley, Okanagan Valley) where high value crops rely on high nutrient application, water, and intense management.

Technology Group	Costs & ROI	Technology Risks & Readiness	Commercial Status	Relevance to BC
Variable Rate Technologies (VRT)	o VRT hardware is typically included in new machinery. However, there would be additional costs for the software and services to use the hardware. o A new purchase for a complete system (e.g., guidance, VRT hardware and software, etc.) may cost \$20,000 to \$30,000. o Costs for agronomist services around VRT typically range from \$5 to \$15 per acre depending on technologies applied, soil sampling, analysis, level of VRT service, etc. o ROI vary due to crop type, soil variability, inputs, technology, etc. Studies have shown a range from \$4 to \$96/acre. o Benefits result from increasing yield, reducing input costs, and managing risks.	o There is considerable risk/ uncertainty around returns, as the results are completely land dependent. o The usefulness of each tool varies from farm to farm and field to field and therefore the best information for VRT management should be gathered at the field level (i.e., within the boundaries of each field).	o The tools for VRT combine hardware, software, and operational techniques and are all readily available. o The present systems are not designed to completely replace industry professionals and farmers in management decisions but to provide information and tools to improve input use-efficiency.	o Variable rate technology is most applicable to annual crops and row crops. o There would be more utility and benefit for VRT in the larger operations found in Williams Lake and Peace River districts. o VRT is most beneficial when a farm has highly variable soil types across the farm.
Guidance and Autosteer	o Automated steering systems range in cost based on the type of technology/level of accuracy. For example, differential global positioning system (DGPS) systems cost in the range of \$13,000 to \$26,000. Whereas, real-time kinematic (RTK) systems cost \$\$26,000 to \$39,000. o Operating costs range from \$1,000 to \$2,600 per year. o In general, the cost of agbots is still high. For example, in trial, Rowbot: was used to fertilize corn at \$13/acre. o ROI for guidance and autosteer is around \$1/acre. o Reduced costs of labour, inputs, and fuel.	o Autosteer and guidance technologies are considered to be risk-free. o Agbots for nutrient management are in their infancy with no commercially available units.	o Autosteer and guidance technologies have been fully commercialized for many years. o Agbot application in nutrient management is still limited with technologies at the early commercialization stage.	o Most guidance and autosteer technologies are focused on row crops (e.g., canola and wheat). o Use in small acreage farms is in its infancy but is likely to grow in the future. Though currently, the cost may be a barrier for smaller farms.

Challenges & Barriers to Precision Agriculture Adoption in BC

Key challenges and barriers identified through this scoping study include:

- **High capital costs (and support needed for small farms):** High capital costs and uncertainties with respect to the return on investment (ROI) given the early stage of precision agriculture technologies in Canada (limited track records). Small farms face additional challenges and limitations with respect to prohibitive capital or operating costs and what technologies are available (e.g., some drone services require a minimum acreage).
- **Risk aversion and limited understanding (and lack of independent experts):** The value of data is not fully understood. There is also a lack of desire and/or ability to interpret and apply the multitude of complex data captured through precision agriculture technologies. Complexity of data and a lack of trusted professionals to interpret and apply the data on a farm-by-farm basis is a major barrier to the adoption of these technologies.
- **Aging farmer population:** Precision agriculture planning may go against intuition and the decades of experience of the farmer. There may not be a big uptake until there is a generational change amongst farmers in BC.
- **Technology limitations:** Some technologies are unsuitable for BC farms due to lack of access to wireless coverage, as well as soil and weather conditions (e.g., some technologies will not work with pooled water or snow pack).
- **Lack of integration of hardware and software:** Lack of seamless integration between technologies, equipment, and data. There is no “system” that will allow for integration of all precision agriculture technologies and data for an all-inclusive, comprehensive nutrient management plan.
- **Data ownership issues (and open data):** Lack of access for farmers to their own raw data. There is a need for an open data concept for precision agriculture technologies for nutrient management applications.
- **Desire to optimize vs. maximize:** The mindset for certain high value crops (e.g., grapes, blueberries, raspberries) is to maximize, not optimize, yields. These growers are not as concerned about how much fertilizer or water they are using, and adoption of precision agriculture technologies will be slower for these areas.
- **Lack of best practice guidance:** There is a need for an agreed upon protocol for best practise and government support for farmers to adopt more precision agriculture technologies in BC.

Benefits to BC Farmers from Precision Agriculture Adoption

While the benefits are difficult to quantify in actual terms for BC farmer operations at present given their low adoption rate, several potential environmental and economic benefits in general terms are listed below, specific to the whole “system.”

- **GHGs and Air:** GHG emission reductions result from an overall decrease in nutrient application, reduced fuel consumption (and associated emissions) from farm equipment, as well as reduced emissions associated with nutrient manufacturing. Note that there has been limited study of the environmental benefits of specific precision agriculture technologies for nutrient management.
- **Water:** Precision nutrient application (e.g., amount, timing, location) leads to decreased nutrient runoff and resulting water contamination.

- **Soil:** Fewer passes for nutrient application results in decreased soil compaction. Precision nutrient application (e.g., amount, timing, location) leads to decreased nutrient runoff and resulting soil contamination.
- **Plant Health:** Increased yield and improved plant health results from more tailored use of nutrients.
- **Economic:** In general, precision agriculture technologies optimize resource use on the farm. This results in reduced input costs (e.g., fertilizer) and reduced fuel costs through some technologies (e.g., guidance and autosteer and VRT). Other technologies help to reduce the cost of labour (e.g., guidance and autosteer) and manage risks (e.g., VRT). In addition, GPS/GIS technologies increase the operational efficiency of production (e.g., better allocation of equipment, reduction in lab sampling costs, reduction in labour requirements, etc.). Economic benefits of precision agriculture technologies also result from increasing yield.

Conclusions & Key Takeaways

As mentioned earlier, the global precision agriculture technology market has been steadily growing. In the US, guidance and autosteer segments appear to have the most potential, whereas in Canada, western farmers tend to consider sensors to be the most beneficial.

From the nutrient management perspective, nitrogen contamination due to fertilizer overdosing is a big challenge for the agriculture sector. Current global nitrogen use efficiency is only 35-40%, meaning that there is a great opportunity to improve the efficiency through accurate rate and timing control on nutrient applications using precision agriculture technologies.

Key takeaways for the BC Ministry of Agriculture to consider when identifying and assessing next steps are listed below.

- BC Farm Sector
  - Highly concentrated, agriculturally dense regions could greatly benefit from precision agriculture for nutrient management; however, the opportunity for application may be lower than other regions due to smaller farm size, cost, and potential ROI.
  - There are fewer barriers facing larger operations with more “prairie-like” production, as well as annual crops, to implementing precision agriculture for nutrient management (e.g., VRT, GPS/GIS, and guidance and autosteer).
- Technology Limitations
  - There is currently no system to integrate all technologies, data, and applications.
  - There are some companies that are working to integrate all different types of data (from different hardware and software technologies) into one platform, who may be able to assist BC farmers in bringing together more holistic systems for technology adoption.
  - The technologies and associated dashboards need to be simple to use with no or very little disruption to current farm management systems.
  - New equipment tends to come equipped with some precision agriculture technologies (e.g., autosteer, VRT), but these technologies are not often being used effectively by BC farmers. There is currently more equipment capacity than actual usage.

- Understanding the Benefits of Precision Agriculture Technologies
  - GHG and air emission reductions result from an overall decrease in nutrient application, reduced fuel consumption from farm equipment, as well as reduced emissions associated with nutrient manufacturing.
  - Precision nutrient application (e.g., amount, timing, location) leads to decreased nutrient runoff and resulting soil and water contamination. Fewer passes for nutrient application also results in decreased soil compaction.
  - Increased yield and improved plant health results from more tailored use of nutrients and real-time monitoring.
  - Economic benefits to BC farmers result from optimizing resource use on the farm (e.g., reduced input and fuel costs) and increasing yields. Additional benefits arise from reduced labour costs, better risk management, and increased operational efficiency.
- Addressing the Main Barriers
  - Behavioural change is required.
  - Increased education and awareness are required.
  - Increased and improved service and consulting is required.
  - Addressing the data concerns will be required.
  - High capital costs need to be addressed.

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1. Introduction and Project Overview

The British Columbia (BC) Ministry of Agriculture is interested in identifying clean technology options that align with provincial priorities; have positive impacts on climate, air, land, and water; and are feasible for implementation in BC. Precision agriculture technologies for nutrient management planning are of particular interest to the BC Ministry of Agriculture, as nutrient loading is a prominent issue in parts of the province. Nutrient management planning is a growing activity for farms throughout the province and the BC Government is assessing technologies that are available to assist farmers in this planning, as well as for long-term, on-farm nutrient management and productivity improvements.

The purpose of this scoping study is to identify and assess precision agriculture technologies for nutrient management that are specifically relevant and applicable in BC.

Project Objectives and Methodology

The Delphi Group, in partnership with Bioenterprise Corporation, conducted an agriculture clean technology scoping study on behalf of the BC Ministry of Agriculture to better understand the potential for precision agriculture and nutrient management technologies to be deployed in BC.

The project included multiple activities:

- A **technology definitional framework and data collection template** were developed to define precision agriculture for nutrient management purposes and to structure the research phase.
- **Scoping research** was conducted in two stages: an initial targeted desktop literature review followed by a series of industry consultations (14 key informant interviews). The focus was on BC-based companies as available, followed by Canadian and international companies with commercially ready products, applicable to BC.
- A **synthesis and analysis of results** from the research phase was undertaken on each of the technology groupings for relevance to the BC farming sector.
- A **final report** was developed, providing an overview of the key findings from the scoping, industry consultation, and analysis.

2. Overview of Precision Agriculture Technology in North America

Precision Agriculture Technologies for Nutrient Management

Precision agriculture for nutrient management is a farming practice that uses data gathering technologies (e.g., proximal and remote sensors), analytics, and precision application controls to guide farm management practices related to nutrient application. "Nutrients" can include synthetic chemicals, naturally occurring compounds, and animal and plant waste. Use of precision agriculture for nutrient management has the potential to improve nutrient use efficiency, as well as farm productivity. Nutrient loading is a prominent issue in parts of BC, and nutrient management planning is a growing activity for farms throughout BC. Improving nutrient use efficiency has the goal of optimizing use to minimize leaching and accumulation.

Precision Agriculture Technology Groupings

For the purposes of this study, precision agriculture for nutrient management has been categorized into three main processes, and further sub-divided into six main groups of technologies. The classification of these technologies is illustrated in Figure 1.

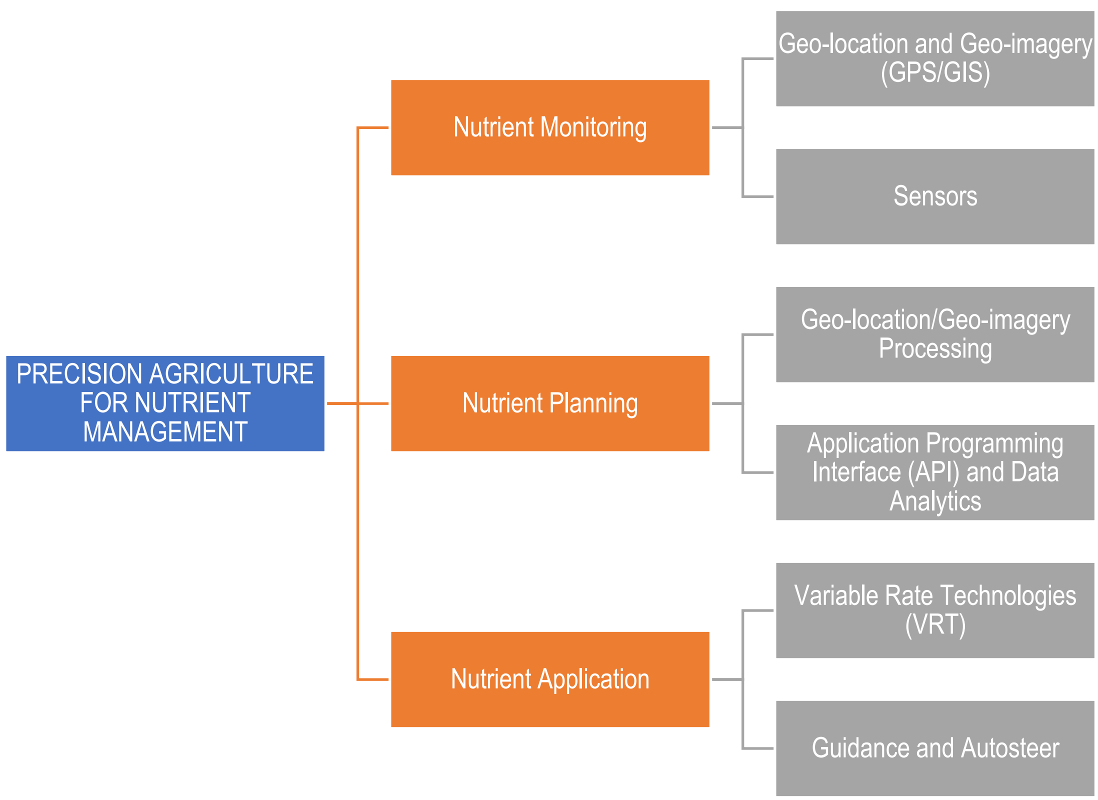

Figure 1 Precision agriculture for nutrient management – technology groupings

Nutrient Monitoring – Technologies that use global positioning systems (GPS)/geographic information systems (GIS) and a variety of sensors (e.g., optical, electrochemical, mechanical, moisture, airflow, temperature, etc.) to capture data pertaining to soil and crop attributes.

- **Geo-location** technologies are central to precision agriculture, as they allow various types of data collected to be overlaid with geographical information. **Geo-imagery** allows for the visual identification of certain variables/indicators.
- A variety of **sensors** used for monitoring variables/indicators, including climatic variables (e.g., temperature, wind, rain, etc.), soil variables (e.g., texture, moisture level, pH, organic matter content, etc.), crop yields, as well as nutrient levels (both macronutrients and micronutrients).

Nutrient Planning – Technologies (hardware and software) that use raw data gathered from the nutrient monitoring technologies for a precise mapping of a field to be used in nutrient planning and application.

- **Geo-location and geo-imagery processing** use photogrammetry and/or spatiotemporal technologies. Photogrammetry converts drone images/satellite images into topography. Spatiotemporal leverages high-resolution aerial imagery to monitor crops for hotspots.
- **Application programming interface (API)** is a platform for sharing data between multiple software and hardware applications. **Data analytics** refers to the analysis of data to help farmers make real-time and predictive decisions, including real-time data visualization, forecasting, and nutrient planning.

Nutrient Application – Technologies capable of applying nutrients (e.g., nitrogen, phosphorus) and soil ameliorants (e.g., lime) in a site-specific manner based on accumulated data recommendations for each sampling point.

- **Variable rate technologies (VRT)** enable variable rate control of inputs for site-specific field conditions. Variable rate technology enables the optimal distribution of resources.
- **Guidance** and **autosteer** are GPS guidance systems to steer a moving vehicle (e.g., tractor, baler, combine, sprayers) automatically. The technology is integrated directly into a vehicle's hydraulics allowing farmers to obtain clear access to cab controls. Agbots, autonomous robots used for the agricultural sector, are also considered within this group. The only agbot identified for nutrient management is Rowbot, which rolls between row crops to spray fertilizers.

It is rare that one of these technologies would be used on its own in precision agriculture, as each depends on or feeds into another. For example, prescription maps can be developed through a combination of GPS/GIS technologies and processing, on-farm and aerial sensors, and data analytics. Prescription maps are then fed into VRT for the application of farm inputs, such as fertilizers. Though Section 4 (Profiles of Technology Groupings) discusses each technology group separately, it should be noted that optimally, the real benefit to farmers comes from applying multiple precision agriculture technologies as a system.

Precision Agriculture Industry Trends

The global precision agriculture technology market has seen steady growth over the last decade, with improved products on the market and higher adoption rates. According to a 2017 study by Stratistics MRC, the global market accounted for $2.81 billion USD (approximately $3.65 billion CAD)[6] in 2014, and is

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expected to increase to $6.43 billion USD (approximately $8.36 billion CAD) by 2022, at a compound annual growth rate (CAGR) of 12.5%.[7] A 2018 study by BIS Research estimated that the market would reach $10.55 billion USD (approximately $13.71 billion CAD) by 2025, at a CAGR of 13.7%.[8] In addition, the global venture capital in agricultural technologies was $10 billion USD (approximately $13 billion CAD) in 2018, whereas it was only $500 million USD (approximately $650 million CAD) in 2013.[9] The key driving forces for the global precision agricultural market include increasing global sales potential; growing demand for food; eminence of wireless, telematics, and "big data" solutions; government interventions; concerns on energy and cost efficiencies; and consumer pressure for more transparency on farming practices (e.g., where their food is coming from, the health of the soil, how environmentally responsible the farmers are, etc.). Compared to cost savings, increasing crop yields and reducing environmental impacts will play a growing role in the future for driving precision agriculture technology adoption.[10]

According to the 18th *Survey of Crop Input Dealers about Precision Agriculture Technologies* study conducted by CropLife magazine and Purdue University in February 2017,[11,12] 81% of dealers offered some type of precision agronomic service to customers. The GPS guidance systems with automatic control for fertilizer/chemical application is the most widely offered technology at 78%. Approximately half of the dealers (52%) are offering remote sensing using aerial/satellite imagery. As for soil sensors, only 9% of dealers offer these technologies to their customers.

In October 2016, the US Department of Agriculture (USDA) published a report to investigate farm profits and adoption of precision agriculture.[13] According to that study, precision agriculture technologies are more likely to be adopted by larger farms. For example, the adoption rate of the largest corn farms (i.e., >2,900 acres) is double the average rate of all farms. It is interesting to observe that the hired labour costs on larger farms with precision agriculture technologies are 60-70% higher than small farms, as the additional labour may be used for information management and other special field operations. However, the percentage of operation costs associated with precision agriculture technologies for large farms are five times lower than that for small farms. In addition, this report indicated that yield mapping has been widely used for corn and soybean farms, and has increased use for peanuts, rice, and spring wheat as well. Since BC is a large producer of wheat,[14] there is great potential for the use of monitoring and mapping in BC farms.

In early 2017, Agriculture and Agri-Food Canada (AAFC) contracted Dale Steele to conduct a Farmer Survey in Western Canada to analyze precision agriculture adoption and barriers in Western Canada, which

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[7] Lamb, J. (2017). *Precision Farming Market Size, Share, Report, Analysis, Trends & Forecast to 2022*. Reuters. Retrieved from https://www.reuters.com/brandfeatures/venture-capital/article?id=14966.

[8] BIS Research. (2018). Global Precision Agriculture Market Anticipated to Reach $10.55 billion by 2025, BIS Research Report. Cision PR Newswire. Retrieved from https://www.prnewswire.com/news-releases/global-precision-agriculture-market-anticipated-to-reach-10-55-billion-by-2025-bis-research-report-899815577.html

[9] Personal communication with precision agriculture expert.

[10] Schimmelpfennig, D. (2016). *Farm Profits and Adoption of Precision Agriculture* (Economic Research Report Number 217). United States Department of Agriculture, Economic Research Service. Retrieved from https://www.ers.usda.gov/webdocs/publications/80326/err-217.pdf?v=0

[11] Erickson, B., Lowenberg-DeBoer, J., and Bradford, J. (2017). *2017 Precision Agriculture Dealership Survey*. CropLife and Purdue University. Retrieved from https://agribusiness.purdue.edu/files/file/croplife-purdue-2017-precision-dealer-survey-report.pdf

[12] Results were analyzed based on 209 completed questionnaires across US.

[13] Schimmelpfennig, D. (2016). *Farm Profits and Adoption of Precision Agriculture* (Economic Research Report Number 217). United States Department of Agriculture, Economic Research Service. Retrieved from https://www.ers.usda.gov/webdocs/publications/80326/err-217.pdf?v=0

[14] Government of British Columbia. Grains & Oilseeds. Retrieved from https://www2.gov.bc.ca/gov/content/industry/agriculture-seafood/animals-and-crops/crop-production/grains-oilseeds-pulse-crops

covered Alberta, Saskatchewan, and Manitoba.[15] According to the 261 responses,[16] which represents almost one million acres of cropland across these three provinces, 84% indicated that they are currently using precision agriculture technologies, and 93% agreed or strongly agreed that precision agriculture technologies are useful. The average cost of precision agriculture is $6.74 CAD/acre. In general, larger and high-revenue farms tend to have higher adoption rates for precision agriculture technologies. In addition, farmers between 35 to 54 years of age appear to have higher adoption rates than the younger and older farmers. As for specific technologies, autosteer systems with GPS guidance are widely used in Western Canada, with an adoption rate of 79%. In addition, 48% of the respondents indicated the use of prescription maps and/or VRT to apply variable (or unique) rates for fertilizer applications, and 36% are using automatic section control for fertilizer application.

Table 1, as well as Figure 2 and Figure 3 below, provide an estimate of the percentage of acres in the dealers' areas (market areas) that use various precision technologies that are relevant to nutrient management in the US. The GPS guidance system with automatic control still shows the highest potential for farmer adoption in the US. Field mapping (with GIS) and VRT for lime and fertilizer application also exhibited great potential for the three years following the study in the US. In contrast, according to the Farmer Survey in Western Canada,[17] respondents (27%) consider sensors to be the most beneficial technologies for their farm business over the two years following the study in Canada, followed by data analytics (19%), crop monitoring (17%), data automation (15%), and autonomous equipment (12%).

Table 1 Producer use of precision technologies, retailers estimate of their market area[18]

Precision Agriculture technologies relevant to nutrient management	Estimated market area (2017)	Estimated market area (2020)
Guidance / autosteer	60%	72%
Field mapping (with GIS)	45%	61%
VRT liming application	40%	51%
VRT fertilizer application	38%	54%
Satellite or aerial imagery	19%	33%
Cloud storage of farm data	14%	32%
Any data analysis service	13%	30%
UAV or drone imagery	6%	22%
Y drops on fertilizer applicator	6%	16%
Telematics	5%	12%
Chlorophyll / greenness sensors for N management	3%	10%

[15] Steele, D. (2017). *Analysis of Precision Agriculture, Adoption and Barriers in Western Canada, Producer Survey of Western Canada*. Prepared for Agriculture and Agri-Food Canada. Retrieved from https://www.realagriculture.com/wp-content/uploads/2017/04/Final-Report-Analysis-of-Precision-Agriculture-Adoption-and-Barriers-in-western-Canada-April-2017.pdf
[16] Of the 261 responses, 46% were from Alberta, 32% from Saskatchewan, and 22% from Manitoba.
[17] Steele, D. (2017). *Analysis of Precision Agriculture, Adoption and Barriers in Western Canada, Producer Survey of Western Canada*. Prepared for Agriculture and Agri-Food Canada. Retrieved from https://www.realagriculture.com/wp-content/uploads/2017/04/Final-Report-Analysis-of-Precision-Agriculture-Adoption-and-Barriers-in-western-Canada-April-2017.pdf
[18] Erickson, B., Lowenberg-DeBoer, J., and Bradford, J. (2017). *2017 Precision Agriculture Dealership Survey*. CropLife and Purdue University. Retrieved from https://agribusiness.purdue.edu/files/file/croplife-purdue-2017-precision-dealer-survey-report.pdf

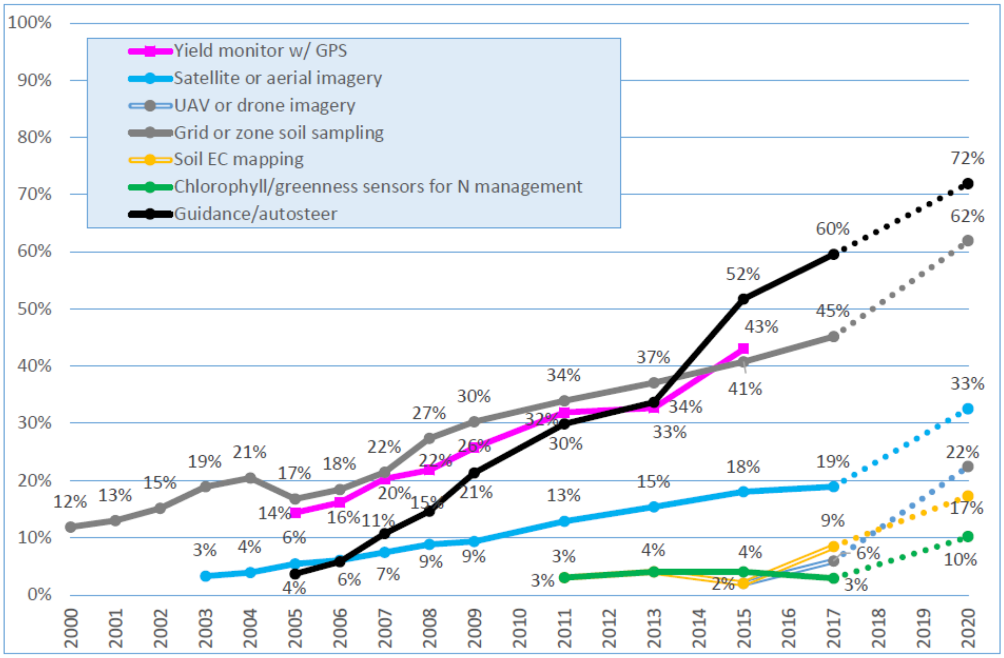

Figure 2 Farmer use of precision technologies, estimated by retailers[19]

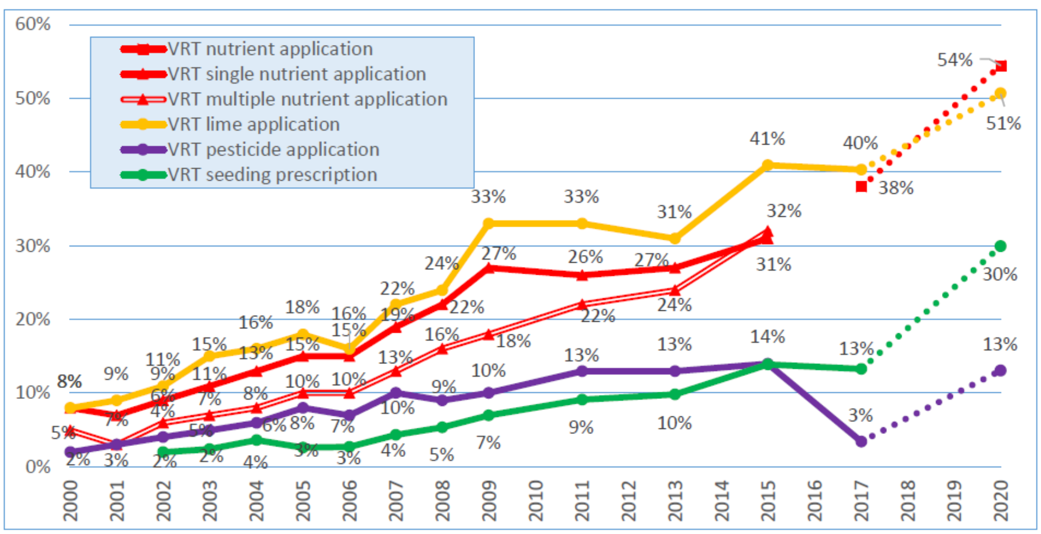

Figure 3 Farmer use of variable rate precision technologies, estimated by retailers[20]

[19] Erickson, B., Lowenberg-DeBoer, J., and Bradford, J. (2017). *2017 Precision Agriculture Dealership Survey*. CropLife and Purdue University. Retrieved from https://agribusiness.purdue.edu/files/file/croplife-purdue-2017-precision-dealer-survey-report.pdf
[20] Erickson, B., Lowenberg-DeBoer, J., and Bradford, J. (2017). *2017 Precision Agriculture Dealership Survey*. CropLife and Purdue University. Retrieved from https://agribusiness.purdue.edu/files/file/croplife-purdue-2017-precision-dealer-survey-report.pdf

3. Opportunities in British Columbia for Precision Agriculture Technologies in Nutrient Management

This section presents an upfront overview of the BC farm sector, a summary of top opportunities for precision agriculture technologies in BC, and key gaps that are relevant to BC. Technologies, opportunities, barriers, and benefits are discussed in detail in Sections 4, 5, and 6.

Overview of British Columbia Farm Sector

In BC, the number of farms has been decreasing. The 2016 Census of Agriculture counted 17,528 census farms in BC, down 11.3% from 2011 and almost double (5.9%) the decline nationally. Total farm area has declined by 0.8% and land in crops has declined 3.1%.[21] Additionally, more than 40% of BC farms are considered small farms, with less than $10,000 CAD in receipts. Because farms are generally increasing in size, the impact of individual farms on the environment is also increasing. However, those farms will also have a higher ability to absorb the costs associated with precision agriculture technologies for nutrient management.

Table 2 Number of farms in key agricultural growing regions by size

Primary Agricultural Regions	Small Farms (under 400 acres)	Medium farms (400 to 2880 acres)	Large Farms (2880 acres and over)
Vancouver Island - Coast Region: Includes CARs 17, 19, 21, 26	1725	16	1
Lower Mainland - Southwest Region: Includes CARs 9, 15	3891	46	3
Thompson - Okanagan Region: Includes CARs 7, 33, 35, 37, 39	4580	264	95
Cariboo Region: Includes CARs 14, 53	545	316	97
Peace River Region: Includes CARs 55, 59	440	469	146

For farmers expanding production, the cost of land may limit the farmers ability to also invest in precision agriculture technologies. The average cost of farmland in BC is double the Canadian average, and even higher in areas located close to urban centres. The Agricultural Land Reserve has improved efforts to preserve what arable land there is for agricultural use, but this has not prevented land prices from escalating.

BC's ideal growing conditions allow farmers to grow over 200 different commodities. Within BC, there are 1,000 grain and oilseed producers, farming over 380,000 acres. Of the total farmland in 2016, 62% was in pasture land (e.g., tame or seeded pasture and natural land for pasture); 23% was is in crops (e.g., hay and field crops, fruits, field vegetables, and sod and nursery products); 14% was used for farmland, and the remaining 1% was summer fallow. BC reported the largest absolute increase among the provinces in the number of farms reporting vegetables, up 289 from 2011 to 2,329 farms. Within BC, all reported crops, excluding tame hay and wheat, are increasing in both average yield and total production. This trend is caused by the improvement of farming efficiency and adoption of precision agriculture technologies. The

[21] Statistics Canada. 2016 Census of Agriculture. Retrieved from https://www.statcan.gc.ca/eng/ca2016

potential application of precision agriculture technologies in BC is also impacted by the diversity of commodities.

The Peace River region in BC has been the main growing region for grain and oilseed crops since the early 1900s. There are 250 producers located in the region alone, accounting for 80% of the provincial acreage and production export.

In the Nechako, Cariboo, and Kootenay regions, the majority of the crops, specifically barley and oats, are used for livestock feed, with minimal amounts harvested as grain.

The area allocated to BC's main field crops is canola (29%), wheat (23%), barley (20%), oats (25%), and peas (3%). The majority of corn grown in BC is used for livestock feed as opposed to a grain crop.[22]

The Southern Interior regions of BC where it is warm and dry is the main growing region for fruit trees and grapes that are used in the wine industry.

The Fraser Valley and Vancouver Island, where is it cooler and wetter, grow high value vegetables, berries, mushrooms, and most of the floriculture and nursery crops. The adoption of precision agriculture technologies in these areas is impacted by the intensity of production, geographic location, and the type of commodity produced.

Population and demand must also be considered. Statistics Canada estimated that the population of BC surpassed five million in 2018.[23] Between 2007 and 2017, the population grew by 12.3%.[24] Increasing population results in increasing demand on production of food crops, particularly under the stresses of climate change, which also impacts availability of imported food (e.g., due extreme weather events in California, Mexico, and other jurisdictions). Precision agriculture technologies can be used in BC to improve productivity and yields of food crops, while also lowering operational costs.

The age of farmers is also a key consideration for the adoption of precision agriculture technology. In BC, farm operators under the age of 35 account for an increasing share of the total operations; these numbers increased for the first time in the last 25 years as of the 2016 Census. From 2011 to 2016, the proportion of farm operators aged 55 years and older in BC rose to 58.5%. However, the proportion of young farm operators (under 35 years old) increased to 6.9%. Over the five-year period, the average age of operators edged up from 55.7 to 56.3 years. Additionally, BC had the highest proportion of female farm operators (37.5%) in Canada in 2016, up from 36.5% in 2011. Nationally, women accounted for 28.7% of all farm operators in 2016.

[22] Government of British Columbia. Grains & Oilseeds. Retrieved from https://www2.gov.bc.ca/gov/content/industry/agriculture-seafood/animals-and-crops/crop-production/grains-oilseeds-pulse-crops

[23] Statistics Canada. (2018). Canada's population estimates, third quarter 2018. Retrieved from https://www150.statcan.gc.ca/n1/daily-quotidien/181220/dq181220c-eng.htm

[24] Statistics Canada. Population. Retrieved from https://www150.statcan.gc.ca/n1/pub/12-581-x/2018000/pop-eng.htm

Table 3 Proportion of farm operators by age group in BC[25]

Age Group	2011 (% of farm operators)	2016 (% of farm operators)
Under 35	5.4	6.9
35-54	40.5	34.6
55 +	54.1	58.5

These data are relevant in that younger farmers may be more likely to adopt new technologies and be more attune to their impact. Positioning of precision agriculture technologies to the market then must take into consideration who is purchasing the technology.

Summary of Top Opportunities for Precision Agriculture Technologies in British Columbia

Precision agriculture technologies for nutrient management have the potential to address some of the major challenges faced by the agricultural industry in BC. For instance, nutrient loading is a prominent issue in BC, particularly in those areas where there are high concentrations of livestock, poultry and eggs, grain crops, and horticultural production. There is a need to continue to develop geo-referenced models to assess and predict climate change's impact on water availability and requirements, greenhouse gas emissions, soil carbon sequestration, soil biodiversity, pest distribution and ecology, and crop distribution with consideration of their vulnerability to environmental risks.

Crop diversity directly impacts nutrient management through crop rotation (with respect to annuals), fertility requirements for perennials, and carbon management (and organic matter care). Poorer soils retain fertilizers to a lesser extent, and therefore will require more supplemental nutrients. It becomes a vicious cycle.

The management of nutrients on-farm can involve many different practices including, but not limited to, composting, tillage practices, residue management, use of cover crops and green manure crops, manure management, crop rotation, fertilizer application, pest management, irrigation, grazing management, and GPS and field mapping. These practices can be complex and require a significant amount of information and data, however, the integration of precision agriculture technologies on-farm can simplify and optimize nutrient management planning.

To determine the top opportunities for precision agriculture technologies in BC for nutrient management, a number of variables must be considered, including farm size, crop type, landscape, and weather conditions. Therefore, there will be regional differences in terms of what technology will be the most beneficial profit-wise and environmentally and this may even differ from farm-to-farm.

Any **sensor** technology that can measure level of nutrients in the soil would give immediate information on what kind of nutrient management is required (e.g., nutrient replacement, maintaining optimum nutrient level). Of nutrient application, planning and monitoring, the latter may be the most important as it provides the groundwork to help determine where the variation in nutrients can be found and where opportunities exist to better manage nutrients.

[25] Statistics Canada. Farm operators classified by number of operators per farm and age, CANSIM Table 004-0239. Retrieved from https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3210044201

Data analytics adoption is not high in the agricultural space, but it is an up-and-coming area on "big data" processing. This is however relevant to those areas that have confined agricultural production (e.g., Fraser Valley, Okanagan Valley) where high value crops and operations rely on high nutrient application, water, and intense management.

Variable rate technologies are especially useful in annual crop production where nutrient management is subject to crop type and the previous cropping system. Perennial cropping systems (e.g., grapes, tree fruits, blueberries) will see less benefit compared to application in high acreage row crops (e.g., grain and oilseed crops in particular). Because these crops tend to be grown on larger operations, their applicability will also be higher and can be used in concert with GPS/GIS systems. Further, use in inconsistent soil conditions will elevate the effectiveness of VRT.

Similar to VRT, **autosteer technologies** are currently geographically limited to areas of high acreage production and GPS/GIS coverage.

Although optimally, monitoring, planning, and application technologies would be used together in a system-wide approach (as further discussed below), it is not likely given the current challenges, not the least of which are initial capital costs and a current lack of interoperability between technologies and technology groups. Instead, a collection of techniques and technologies to collect, analyze, and use data are selected based on overall farm profile, which are different for each location, crop, terrain, and soil type.

Key Gaps

Ideally, taking a "systems" approach to precision agriculture would integrate all relevant technologies which would capture both localized micro environmental data as well as macro level information. Realistically, producers are employing some of these technologies to meet their environmental responsibilities and at the same time maintain their own business sustainability. It is however unrealistic to presume that producers will use all technologies but use of some technologies in precision agriculture will lead to both enhanced profitability with consequent favourable environmental impacts. At this time there is no "system" that will allow for integration of these technologies, and the data collected by each, into one system for an all-inclusive, comprehensive nutrient management plan. There is a need for an open data concept for precision agriculture technologies for nutrient management applications.

Additionally, there are other challenges associated with the BC farming landscape and the applicability of these precision agriculture technologies. For example, in the regions of BC where they grow a significant volume of grapes, blueberries, and raspberries, growers are not as concerned about how much fertilizer or water they are using because they are growing such high value crops. They are interested in maximizing, not optimizing, yields. In these areas, adoption of precision agriculture technologies will be slower.

As well, a large percentage of farms in BC are considered small farms. This puts a limitation on some technologies, such as certain drone services that require a minimum acreage in order to see a return on investment. Other technologies, such as hyperspectral imaging analytics have a high capital or operating expenditure associated with application and therefore would not make sense financially for a small farm.

In addition, the complexity of the technologies and associated data can be a major barrier to the adoption of these technologies. A significant gap is the lack of trusted professionals that have a deep understanding and knowledge of the precision agriculture technologies that exist for nutrient management. There is a need for industry experts that can work with farmers on a case by case basis to identify what technology would be best suited and provide the most benefits to their specific operation.

Getting the agricultural industry to agree on what is best practise is also a major gap and barrier to precision agriculture adoption. As quoted by one entrepreneur “if you put 10 agronomists in one room, you will get 15 opinions.” There is a need for an agreed upon protocol for best practise and government support by way of subsidies to support farmers to adopt more precision agriculture technologies in BC.

4. Profiles of Technology Groupings and Outlook for Application within British Columbia

Geo-location and Geo-imagery

Introduction to Technology Group

Global positioning systems (GPS) and geographic information systems (GIS) are essential for the development of precision agriculture in the BC market and will assist growers in unique farming environments to establish environmentally friendly yet economically efficient resource utilization. Geospatial data can be captured from a number of different acquisition technologies including satellite, aerial, drone, and on-the-ground technologies, each providing different degrees of resolution and geospatial relevance.

Satellite-based geospatial technologies have the advantage of being able to monitor large geographic spaces (Figure 4), and with the advent of new sophisticated technologies, can monitor and detect changes in attributes such as crop health, topography, and soil moisture. Aerial-based technologies will have similar capacity but at a more limited geographic swath. The advantage of using drone technology is to increase the pixel resolution per acre thereby allowing for more specific analysis than that which is available from satellite-based technologies. On the ground and in ground geospatial technologies enable the capture of geo-referenced micro level data, such as crop metabolism, transpiration, and gaseous exchange (CO_2, O_2).

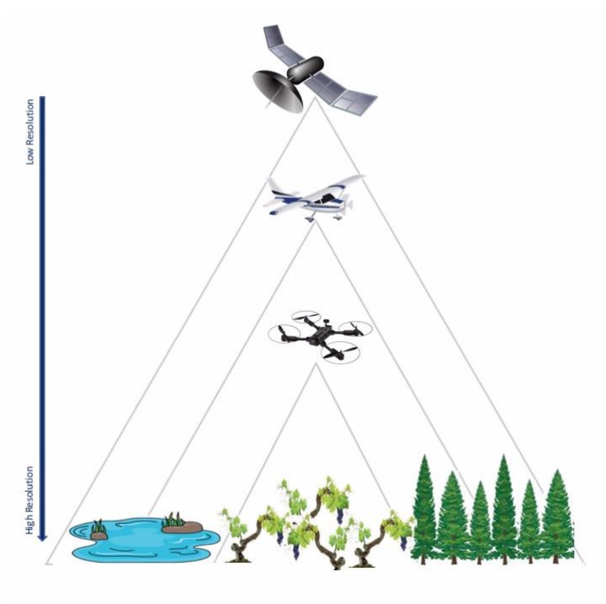

Figure 4 Geographic capacity and resolution of geospatial technologies (image adapted from Rezatec)[26]

[26] Image source: Rezatec https://www.rezatec.com/

Some imaging technologies measure the amount of incident energy that is reflected by vegetation, soil, and other artefacts in the cultivation. The geo-referenced sensors have varying spatial, spectral, radiometric, and temporal resolutions. Other sensors that can be used include light detection and ranging (LIDAR), synthetic aperture radar (SAR), and earth penetrating radars. Examples for the use of LIDAR on aerial technologies include developing topographic or elevation maps of a field in a very short time, with LIDAR providing resolutions in centimeters/inches. In addition, GPS/GIS/aerial technologies can monitor the physical and chemical properties of soil, including soil types, texture, organic matter, and pH. Soil nutrient data includes soil nitrogen, phosphorus, potassium, and other large numbers of nutrients.

These systems are extremely data intensive because of real time data collection, global positioning, and data interpretation. GPS/GIS technologies are used in concert with farm management, field and soil monitoring, pesticide and fertilizer input decisions, mapping for field conditions (e.g., moisture, crop scouting and vigour, fertility), and seeding to harvest crop management.

Costs

CAPEX, OPEX, ROI as available

There is typically no capital expenditure (CAPEX) for producers using GPS/GIS technologies, particularly for satellites and aerial technologies. However, in some circumstances, producers may want to invest in their own drones or on-the-ground GPS/GIS equipment. In these cases, the farmer would have both CAPEX and operating expenditure (OPEX).

The OPEX cost to growers depends upon the service they are looking for. These can range from a basic service starting around $1.50 USD (approximately $1.95 CAD)/acre and to more advanced packages up to $7 USD (approximately $9 CAD)/acre. A basic service would include numeric data or vector data, while more advanced packages would include layers of GIS, including polygons, lines, points, and raster images, presented as separate layers together as one map.[27] There are volume discounts depending upon the size of the operation as well as costs associated with annual web-based subscriptions. These costs are dependent upon the level of support the supplier provides. In some circumstances, certain costs are not part of the provided service and lead to additional costs. These costs could include GPS, geospatial imagery, and/or equipment inputs which use the internet of things (IOT) (e.g., tractors, sensors, etc.). GIS provides the map polygon for the GPS technology to identify the position and movement within the polygon. Internet of things data provides specifics of the characteristics within the polygon.

For comparison, in the US, services may cost from $7.50 USD (approximately $9.75 CAD)/acre for raw image files to $44 USD (approximately $57.20 CAD)/acre for a normalized difference vegetation index (NDVI) image. The costs for remote sensing from manned aircraft range from $0.75 to $2.30 USD (approximately $0.98 to $2.99 CAD) per acre. The costs for satellite data are low per acre but have high total cost because commercial providers require a minimum area for coverage.

Return on investment (ROI) should not be limited to only looking at the costs associated with GIS/GPS technologies for nutrient management. The initial cost may be high for a single task (i.e., nutrient management), but the same unmanned aerial vehicle (UAV) could be used for multiple tasks. For example,

[27] Syracuse University Libraries. GIS (Geographic Information Systems), Geospatial Data: Types of GIS data. Retrieved from https://researchguides.library.syr.edu/c.php?g=258118&p=1723814

following crop development during the growing season, following pest progression (e.g., weeds, insects, disease), and estimating yield at harvest are all potential uses of the UAV that could impact the optics (and decision) of the investment.

One of the companies interviewed stated that the ROI for their technology was typically around $20 CAD/acre and could be as high as $75 CAD/acre. A key reason for implementing these technologies is to increase the efficiency of production and minimize environmental impacts. One example provided was that of a 10,000-acre Hutterite colony which had invested in 5,000 new acres. By using GIS/GPS technologies, they increased their operational efficiency with a margin of 45% through better allocation of equipment (with associated reduced capital expenditures on new equipment), use of agronomists, a 50% reduction in lab sampling costs, and also a reduction in labour costs.

Technology

Readiness/commercialization stage

A key advantage of these systems is that there is familiarity in the agriculture sector for the use of GPS/GIS. Remote sensing and GIS have emerged as effective tools for the macro and micro level mapping of natural resources.

Companies are developing new uses for GPS devices. GPS can be integrated into smartphones, hand held devices, UAV's, and satellite technology, all of which lead to mapped fields for farmers to apply site specific and precise solutions for their nutrient management issues. For example, UAV-based remote sensing applications for various agriculture applications have soared over the last decade because of their potential to be a low-cost, accessible, and practical substitute for satellite and micro aerial vehicle (MAV) technologies.

Part of the challenge for the adoption of this technology is the readiness of farmers to accept the technology. There are cases where farmers don't have the budget for GPS/GIS technologies as it would be a new expense for them. This forces them to come up with the money and justify that it is helping their bottom line. It has been suggested that having the government agree upon protocols (e.g., nitrous oxide emission reduction protocol - NERP) and providing subsidies will allow for more adoption of these types of technologies.

General risks/uncertainties associated with the technology

A number of technical challenges have led to uncertainties in the uptake of these technologies by producers. Current satellite technologies in operation range in age from 1977 to present day. The Canadian-based satellites are primarily RADARSAT-2, while other global providers have technologies including RGB (red, green, blue) optical, LIDAR, near-infrared (NIR), and limited multi-spectral imaging. Satellite-based remote sensing in precision agriculture are still limited by the coarse spatial resolution, cloud interference during image acquisition, and slow turnaround. Most of the high-resolution satellites used for precision agriculture are not equipped with a high-resolution thermal band, and the spatial resolution of the thermal band is not able to assess crop water stress at field scale. Future technologies will include hyperspectral imaging, a technology that has more capability in this area than those previous, however these are not available to the commercial market yet.

For growers, nutrient deficiencies are hard to detect with current satellite imagery because these deficiencies do not happen uniformly across the field. Further, once these deficiencies are detected, it's almost too late because they are informed by the characteristics of the crop stand. Once hyperspectral imaging becomes the norm, nutrient deficiencies will be detectable on bare ground prior to planting. This will lead to the precision application of fertilizers and other crop enhancers using variable rate technology at planting.

In addition, data formats are also constantly changing. For individual companies, the challenge is to determine which of the hundreds of data types to pursue, and how to engineer the data for acceptance into various platforms. Data platforms need to be compatible with old and new machinery. File sizes for imaging environments are massive and are often measured in multiple gigabytes, which is a challenge for older machinery.

Environmental Benefits

Air, water, land

Environmental benefits are not directly applicable to GPS/GIS technologies. However, remote sensing with imaging spectrometers is an important method for assessment of soil variation, specifically organic matter content. Soil properties are continuous over a landscape with few abrupt transitions and to simplify management, variations are often used to divide a field into management zones, with different zones receiving inputs tailored for those zones. Precision agriculture imaging is used at the detection, identification, localization, and validation steps of nutrient management.

Nutrients, yield, plant health

Precision agriculture can provide early detection of stress, thus, can facilitate improved agronomic practices where UAVs are responsible for spraying chemicals on crops. The application of chemicals is controlled by the feedback obtained from a wireless sensor network deployed on the crop field, ensuring efficient use of nutrients. Certain GPS/GIS are mature technologies (primarily RGB for optical imaging, measuring reflectance and colour intensity, as well as NDVI for thermal spectrum in the infrared bands for differentiation of plant conditions) that can identify crop stresses such as nutrient and water stress, disease, pest, and weed infestation. Geo-imagery enables farmers to identify problems and take immediate or long-term (year-over-year) action, which improves overall crop yield and health. For example, geo-imagery pest management can have a direct and immediate impact on the efficiency of production (and yield), impacting nutrient use. To identify nutrients in the soil, higher level and more recent technologies include multispectral and hyperspectral imaging. Some data can be derived from multispectral images, but more complex profiles require hyperspectral resolutions.

Other

In the past, it was difficult for farmers to correlate production techniques and crop yields with land variability. This limited their ability to develop the most effective soil/plant treatment strategies that could have enhanced their production. Today, GPS/GIS technologies enable farmers to visually link field variability with levels of productivity and other variables, ultimately reducing expenses, producing higher yields, and creating a more environmentally friendly farm.

Commercial Success

Market info

GIS/GPS technologies have been on the market for more than 30 years and are well understood. Application of the technologies is limited by the producer's ability or willingness to pay for the technologies.

General barriers

A potential barrier is access to these technologies by the producers. To address this, one of the companies interviewed sells their technology through a dealer network and input suppliers and provides support to growers through this network. Additionally, having personnel with expertise in precision agriculture will reduce the risk to growers in their adoption of these technologies. This approach has allowed this company to extend its reach through 156 countries, serving 1.6 million acres.

There is a history of farmers not having a good experience with technology and service; even services such as basic soil testing are not done by the majority of producers. In the western provinces, for example, adoption of basic soil testing is about 25%. A perception that exists is that companies have done a poor job soil testing, had limited policies and procedures, and inaccurate soil collection, resulting in poor data. There is a need for re-education about precision agriculture technologies, particularly those that may seem more advanced or complex, such as GPS/GIS, for farmers and the risks associated with adoption and non-adoption.

Competitiveness and alternatives

There are a number of technologies (e.g., handheld GPS, UAVs, satellites, etc.) within this grouping that all do similar things. Each has its own pros and cons and need to be considered on a case by case basis.

Relevance to BC Farming Sector

Market potential in BC

Given the breadth of GPS/GIS technologies, there is market potential in BC, depending on the farmers requirements, topography, and crop type, etc. Initial farm mapping could be provided by various types of geospatial imagery however, in mountainous territory like BC, angle of incidence of the image can affect the accuracy of the polygon shapes and relief. However, with basic field imaging, ground proofing of the satellite imaging with on-equipment GPS could provide accurate location and shape of field polygons and provide the potential for improved nutrient sensing, either by UAV or on-equipment. Ground proofing involves the validation of the image coordinates by visiting the identified coordinate location on the ground and ensuring accuracy of the data point for the border of the field polygon.

Drone technologies are most applicable to places where crops are on hillsides or steep slopes. Ground proofing can be done with drone positioning in a similar manner to the on-equipment GPS technologies. Lower altitude drone technologies would also have use in the Okanagan and Fraser Valleys where farm size is smaller, but land is highly productive and subject to significant management. Satellite imaging and high-altitude drone technologies would likely have good application in large scale farming operation areas like the Peace River District and Williams Lake.

BC specific risks/uncertainties associated with the technology

General earth imaging (geospatial) from satellites is limited by the field of view especially in mountainous areas, and the environmental/climatological barriers that may exist (e.g., clouds, fog, rain, smoke). As a result, near ground or on-ground equipment or in-ground sensing may provide the most reliable and immediate opportunity to collect data particularly with respect to nutrient profiles.

Barriers/challenges specific to BC

Distribution of service providers for identifying farm coordinates and field coordinates are likely located in either the areas of the Okanagan or the Fraser Valleys. Application for these services in other in-land areas may be cost prohibitive from a travel and operations perspective for the service provider.

Sensors

Introduction to Technology Group

Sensor technologies can be found in a variety of different areas related to agriculture nutrient management. These would include sensors like yield monitors, hand-held spectrometers, hyper-spectral camera drones, soil sensors (e.g., nutrients, water, soil structure), and weather/climate monitors. Sensors in nutrient management are a relatively recent development and have been augmented through the development of microelectronic sensing technology and the advent of the internet of things (IOT) for the transmission of data. The efficiency in transmission rates, types of data, and ability to interpret these data increase the utility of these technologies. Companies are developing new technologies in this field and in general the field is growing. Innovations are being developed through small or medium size enterprises and the incorporation of artificial intelligence algorithms and the interpretation of the data in real time is leading to opportunities in electronic nutrient management sensing.

Multiple sensors are used in precision management for nutrient management. Soil sensors can be electrochemical (Figure 5), electrical or electromagnetic, optical (Figure 6), radiometric, acoustic, or mechanical.

Figure 5 Electrochemical sensor for soil pH mapping[28,29]

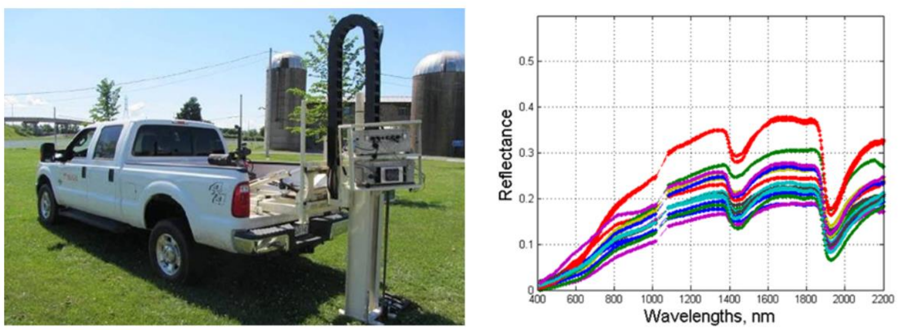

Figure 6 Optical sensor with visible and near-infrared spectrum (left) and soil spectra obtained from the optical sensor (right)[30]

Soil sensors can be used for on-site soil assessment to generate real-time soil data such as pH, electrical conductivity, salinity, dissolved oxygen, nutrient concentration, and more (Figure 7). This information can be tied to GPS data to generate maps to efficiently display nutrient variability to be used for site-specific nutrient application. For example, Figure 8 shows a non-contact electromagnetic sensor for soil mapping. This type of sensor is used to measure the electrical conductivity of the soil. It does not make direct contact with the soil and is usually used together with a GPS receiver on a moving vehicle.[31]

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[28] These sensors measure voltage, which is translated to a concentration of ions.
[29] Image source: Folnovic T. *Smart sensors for accurate soil measurements*. Retrieved from http://blog.agrivi.com/post/smart-sensors-for-accurate-soil-measurements
[30] Image source: Folnovic T. *Smart sensors for accurate soil measurements*. Retrieved from http://blog.agrivi.com/post/smart-sensors-for-accurate-soil-measurements
[31] Folnovic T. *Smart sensors for accurate soil measurements*. Retrieved from http://blog.agrivi.com/post/smart-sensors-for-accurate-soil-measurements

Soil property[1]	Sensor type							
	Gamma-ray	X-ray	Optical	Microwave	Radio wave	Electrical	Electrochemical	Mechanistic
Chemical								
Total carbon	D	D	D					
Organic carbon	I		D					
Inorganic carbon	I		D					
Total nitrogen	D	D	D					
Nitrate-nitrogen			I		I	I	D	
Total Phosphorus	D	D	I					
Extractable phosphorus								
Total Potassium	D	D	D					
Extractable potassium			I				I	
Other major nutrients	D	D	D					
Micronutrients, elements	D	D	D					
Total Iron	D	D	D		I			
Iron oxides	I		D		I			
Heavy metals	D	D	I					
CEC	I		I			I		
Soil pH	I		I		D		D	
Buffering capacity and LR			I				I	
Salinity and sodicity					D	D	D	
Physical								
Color			D					
Water content	D		D	D	D	D		I
Soil matric potential	I					D		I
Particle size distribution	I		I		I	I		I
Clay minerals	I	D	D			I		I
Soil strength								D
Bulk density	I		I		D			I
Porosity								D
Rooting depth					I			D

[1] – soil properties directly (D) or indirectly (I) predictable using different types of proximal soil sensors

Figure 7 Predictability of soil properties using different soil sensing concepts[32]

Figure 8 Non-contact electromagnetic sensor for soil mapping[33]

Climate/weather monitors are also used to inform nutrient application. For example, nutrient application may be delayed if a heavy rain event is predicted to occur. Similarly, data from yield sensors can be used to inform future prescription maps. There are new techniques to identifying soil macronutrients (NPK), micronutrients, and trace minerals in addition to soil types, and organic matter. Figure 9 shows a battery-powered, wireless, meter-long soil sensor probe developed by Teralytic. Different types of sensors can be used inside the probe to measure surrounding NPK levels, temperature, moisture, salinity, as well as aeration, and respiration.

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[32] Image source: Adamchuk V.I. et al. (2011). Chapter 2: Sensor Fusion for Precision Agriculture. In Thomas, C. (Editor) *Sensor Fusion – Foundation and Applications* (pp. 27-40). Retrieved from https://www.ars.usda.gov/ARSUserFiles/50701000/cswq-0454-adamchuk.pdf.

[33] Image source: Folnovic T. *Smart sensors for accurate soil measurements*. Retrieved from http://blog.agrivi.com/post/smart-sensors-for-accurate-soil-measurements

(a) (b)

Figure 9 Teralytic soil sensors[34]

Costs

CAPEX, OPEX, ROI as available

The costs associated with sensor technology are driven by the business model of the individual company involved. The financial model approach by the various companies in this field differs. Some companies work off high CAPEX for sensor packages and provide low cost data service and analytics while others operate with a relatively low CAPEX and high OPEX. The resulting packages either require a high upfront payment by the producer with a relatively low cost for operation or a more affordable initial purchase price with data access costs significantly higher over the term of the agreement.

The costs associated with sensor technologies can include the cost of the sensors as well as the dashboard and analytics. Some companies will provide a bundled cost for the sensors and associated transmission of the data. However, integration/application of that data, such as GPS inputs, geospatial imagery inputs, or equipment inputs would be outside their scope and would therefore be an additional cost to the farmer.

As noted, the CAPEX for sensor technologies includes both that of the sensor and the cost associated with transmission of the data. The cost for each type of sensor has been declining as manufacturing processes are improved and new technologies are developed. For example, a new wireless NPK soil sensor can be $1,400 USD (approximately $1,820 CAD) to set up (involving installation and the power source) in addition to an annual fee of $500 USD (approximately $650 CAD)/probe. This new wireless NPK soil sensor has been priced in line with traditional soil moisture sensors. Depending on the type of sensor, costs can be dramatically different. With respect to total costs, the number of sensors needed per farm depends on crop type and topography. Annual subscription fees generally cover the dashboard (user interface) and analytics.

According to data from Reuters, the ROI is low in the sensor industry at 4.88%. However, in speaking directly with soil sensor companies, it was clear that no sensor/company specific ROI data has been studied

[34] Image sources: (a) Teralytic https://teralytic.com/probes.html;(b) Albrecht, C. (2018). *Teralytic Sensors Help Farmers Manage Their Fertilizing*. The Spoon. Retrieved from https://thespoon.tech/teralytic-sensors-help-farmers-manage-their-fertilizing/

to date. Return on sensors will likely be as a result of the use of variable rate technologies for nutrient applications in conjunction with the sensors. Sensors provide the information and data required to optimize resources on-farm. For example, the John Deere manure sensing system (available only in Europe) uses on-board sensors to analyze manure nutrient content in real-time and adjust application as necessary based on pre-defined requirements of the fields. This optimizes the use of organic fertilizers in the field, reducing cost of spring fertilization while maximizing crop yield potential. It also eliminates the cost and time required for lab analysis of the manure. Potentially, the system could reduce fertilizer costs by 1€ (approximately $1.50 CAD)[35]/kg of N. This information is included for information only, as the technology is not yet available in North America.

Technology

Readiness/commercialization stage

Over the last decade, more and more data has been collected on-farm using technologies such as sensors, portable devices, drones, and smartphones. Not only have there been advancements in the technologies, but the types of data that are being collected has also transitioned from gathering simple numerical values (e.g., yield, water quality) to include more quantitative information for qualitative applications (e.g., odour). Numerous sensor technologies relevant to nutrient management are available on the market today with new, more advanced sensors coming down the pipeline. For instance, the new wireless NPK soil sensors have just become available for the 2019 growing season.

In contrast, the new manure sensing system which accurately applies organic fertilizers (e.g., cattle manure, pig manure, and biogas liquid digestate) to the field is only currently available in Europe and there are no alternatives available elsewhere.

Sensor data collected can typically be customized for each farm by crop and soil types. Some sensors require their own dashboards however use of an application programming interface can address the issue of multiple inputs. Some sensor companies have been certified for data transparency, and all the data are owned by the farmers.

General risks/uncertainties associated with the technology

There are some risks and uncertainties associated with sensor technologies. For example, prediction accuracy is based upon the veracity of the data and a lack of data limits the accuracy of artificial intelligence predictions. This risk can be mitigated by increasing the volume of data. The use of artificial intelligence in these types of sensors is therefore currently limited. There are some technology gaps for optical based sensors that track and monitor nutrient deficiencies. Usually by the time the nutrient deficiency is captured by the optical sensor, it may be too late for a grower to do anything about it (i.e., efficiently manage the nutrients). Some sensors are limited by their environmental tolerance. For example, some require moisture to operate, some are not robust in adverse weather conditions, low temperatures being one of them. As well, communication of sensors with the central controller without any interference and at a low rate power consumption can be a challenge, especially in high density sensor networks where sensors are located at large distances from each other.

[35] Conversion assumes 1 € = 1.5 CAD.

Environmental Benefits

Air, water, land

In North America, large-scale crops receive up to 50% more fertilizer than the plants can absorb. This surplus of nutrients from both crops and livestock operations contribute to global warming as they end up either as a source of water pollution or as a greenhouse gas. Soil health and soil contamination are also impacted by overuse of fertilizers. Real-time soil sensors can measure site-specific nutrient needs and reduce the recommended fertilizer quantities that are required/applied (through variable rate applications). In speaking with soil sensor companies directly, however, they were unaware of concrete studies that have been done so far to investigate the environmental benefits from the use of soil sensors. In searching the scientific literature, it is clear that the use of soil monitoring sensors can impact farmer decisions in soil management.

Using real-time sensors reduces environmental hazards due to accurate fertilization. The accurate use of fertilizers will reduce the risk of water contamination and the sensors will enable the use of variable rate fertilizer to optimize the use of inputs in crop production.

Nutrients, yield, plant health

Data from sensors helps farmers to use fertilizers more efficiently and to get better crop yields. Sensors are used to determine the most productive zones across a field using historical yield data. By identifying the high and low productivity management zones, farmers can focus inputs and efforts on the highest quality/productivity zones more intensively. For example, combining sensor data with a variable rate application could potentially increase yield by up to 6 dt/ha in corn and 30 dt/ha in forage corn.

Other

The on-going development of soil sensing technologies continues to become more complex. With the ability to transmit large packets of data at a relatively low cost and the development of multiplexed sensors which allow for measurement of many parameters, soil sensing technologies will improve the accuracy of farming, resulting in environmental benefits and improved bottom lines to producers now and into the future. In coming years, it is likely that we will be able to sense and monitor micronutrients, carbon balance, specific soil fertility, contaminants, and other elements that impact both productivity and environmental responses.

Commercial Success

Market info

Yield monitors that can capture spatial detail are now standard equipment for most companies and the use of this technology has increased significantly over the last 20 years. In speaking with soil sensor companies, it is known that wireless nutrient soil sensors are still at the early commercialization stage. Pilot studies have been performed in some areas across the world and production is being ramped up to the scale of interest. It should also be noted that in-situ soil sensors are not meant to completely replace traditional soil sampling and lab analysis, but to complement an annual soil lab analysis to get a complete and ongoing picture. Water monitoring sensors are readily available, as are soil moisture sensors. The John Deere manure sensing system that is currently only available to a few selected European markets will soon expand to EU28+ countries.

General barriers

Soil sensors are very easy to use. They are applicable to any soil type, with the possible exception of dry farm land (some sensors need moisture to function properly). They also work in shallow soils as well. Some sensors need to be placed in soil rather than in gravel or rock since they require good "sensor-to-soil" contact for data transmission. As part of the installation, sensors have to be calibrated before use. Therefore, regional calibration issues are not a concern. Some sensors are installed after planting and taken out before harvest as they cannot be in the fields when there is a lot of heavy equipment activity. In addition, sensors have to be removed from the soil before the ground freezes.

Competitiveness and alternatives

Declining costs of sensor technologies have allowed farmers to monitor factors such as soil health, soil moisture, and other parameters in almost real time conditions. Compared to variable rate technologies, sensors are being widely adopted by farmers due to the simplicity and ease of use. They provide valuable information without a lot of work or skills required by the farmer. There is a lot of opportunity to pair in-situ monitoring (sensors) with model predictions and artificial intelligence in the future (which is currently not available on the market).

Relevance to BC Farming Sector

Market potential in BC

Sensor technology packages are decreasing in size and price and are being made available to smaller farm operations through after-market sales efforts, focusing on upgrading older equipment and providing the desired data for soil and nutrient condition on-farm. This fits well with both the size of and equipment availability in the BC marketplace. Terrestrial soil sensors (e.g., Teralytic) would be beneficial to BC farmers to asses general soil profiles, nutrient profiles, and micro nutrients. Sensor technologies specifically would be useful in the Okanagan Valley and Fraser Valley where long and narrow farms are present. Sensor technologies on-equipment (e.g., collecting data on field passes) would also be useful in high plateau areas with cropping and forage development.

BC specific risks/uncertainties associated with the technology

Exposure to harsh environments limits the life of many sensor packages. Replacement of failed units could have a negative effect on the cost of ownership and ROI. For instance, in-ground soil sensors may be damaged by extreme weather or wildlife encounters. In addition, the lifespan of sensors, such as soil moisture sensors is typically only about three years.

Sensor technologies are becoming more affordable, however, the installation and calibration of equipment before use generally requires technical expertise, which may or may not be available in certain regions of the province.

Barriers/challenges specific to BC

Return on investment is a major challenge in the adoption of sensor technologies by agriculture producers in BC. There is a risk/challenge associated with the perceived value of the technology for smaller farms. Any technology deployed must have a perceived benefit (e.g., financial, environmental). Declining costs are making sensors more accessible to a wider range of famers, but a specific ROI is still difficult to predict, as the return in fact results from the use of other technologies (e.g., VRT) in conjunction with the sensors. A more defined/certain financial benefit would have a larger impact on potential uptake of the technology, but this will remain a challenge moving forward given the dependence of return on the application of complementary technologies. As sensor technologies evolve, the increasing simplicity and ease of use, as well as stability/longevity of the technologies have had a positive impact on the adoption rate.

Geo-location and Geo-imagery Processing

Introduction to Technology Group

Geospatial analytics involves analysis of the positional information captured by sensor technology related to geographical systems. Geospatial data is captured from a variety of acquisition technologies including satellite, aerial, drone, and on-the-ground technologies, each providing different degrees of resolution and geospatial relevance. From an agricultural perspective, geospatial analytics can be used in forecasting weather, understanding biodiversity, impact of land use, emerging diseases, and for forecasting the impacts and mitigation of climate change. From a nutrient management perspective, geospatial analytics can monitor and analyze criteria such as topography, soil moisture and structure, weather informatics, crop metabolism, transpiration and gaseous exchange, and cropping systems to predict agriculture impacts on nutrient application and environmental monitoring.

Raw geo-imagery files are obtained from the GPS/GIS acquisition technologies to be processed, analyzed, and turned into useful output for farmers and agronomists, such as topographical maps, biomass maps, plant health maps, and prescription maps, etc. GPS/GIS technologies allow for complex data collection, which in turn are processed and interpreted for the benefit of the farmer. For example, one company's technology provides 25 mapping layers, including micro- and macronutrients, texture, and complex models, as individual components which can then be prioritized by the producer. Another company uses its spatial platform to map profitability across the field with a focus on ROI, profit per acre. An example of the process and result is shown in Figure 10 and Figure 11.

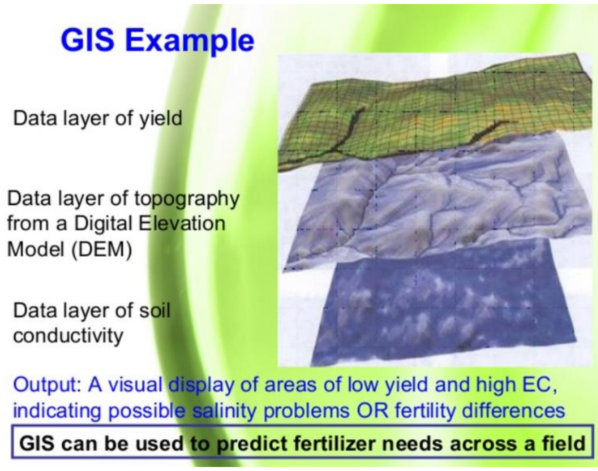

Figure 10 GIS example[36]

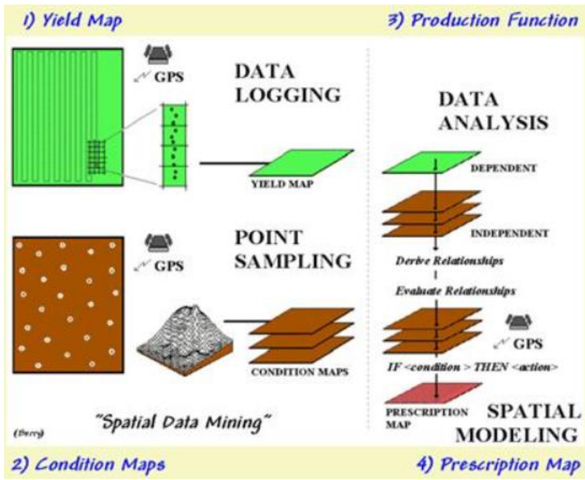

Figure 11 Illustration on how to use GPS and GIS technology to maximize crop yields[37]

Costs

CAPEX, OPEX, ROI as available

Geospatial analytics is often performed by third party companies. Some of the hardware technologies that generate data only manage the raw data. The analytics companies focus on processing technologies that convert the raw data into useful information. For example, many geospatial analytics platforms use licensed satellite data or information from a contracted UAV conductor. Therefore, the only CAPEX required from farmers is related to their choice of tool for viewing/using the processed data (e.g., cell phone, tablet, computer, etc.). There have been some mergers of data collection services and analytics to form a single

[36] Image source: Mitran, T. Precision Agriculture in relation to Nutrient Management. Presentation, Agricultural Chemistry and Soil Science. Retrieved from https://www.slideshare.net/tutan2009/precision-agriculture-in-relation-to-nutrient-management-by-dr-tarik-mitran
[37] Image source: Phelan, Q. *Precision Farming Systems*. Retrieved from http://home.earthlink.net/~qphelan/id73.html

point of capture processing and analytics presentation. This is a growing trend. However, for the most part, the real costs for farmers is OPEX, though there are exceptions. For instance, some producers may choose to invest in drone equipment, or on-the ground GPS/GIS technologies, but pay for a service for data analytics and visualizations.

The cost for OPEX for geospatial analytics typically includes those of data acquisition, data analysis, and interpretation. Data acquisition OPEX costs could include the engagement of a service provider to acquire relevant geospatial data. For example, a company could be requested to come in to do multiple surveys through drone fly-overs with the respective sensors to acquire the data concerning nutrient management of the farm. One service provider company's approach is to provide geospatial analytics information over the course of the growing season, from bare ground, through seeding and flowering, to growth monitoring, to harvest. These surveys are done on a relative time series throughout the growing season.

OPEX for a traditional user would include paying a subscription fee to use the analytics platform and their custom prescriptions. Subject to the sophistication of the information required by the grower, the OPEX will vary depending on the number and quality of the data sources. The annual cost of a typical full geospatial analytical service, including satellite imagery analysis, variable rate prescriptions, and some scouting services, is approximately $10,000 USD (approximately $13,000 CAD) per farm or less, depending on the size of the farm. For smaller farms (e.g., less than 2,000 acres), a unit service fee of approximately $5 CAD/acre is applied and capped at $10,000 CAD. If additional services are required as part of the complete precision agriculture system (e.g., soil sampling), additional fees apply. For example, soil sampling/analysis fees vary based on the types of lab services (ranging between $40-60 USD or approximately $52-78 CAD per sample).

Some geospatial analytics companies have done economic analysis on the application of geo-imaging technology in nutrient management. In general, the use of geo-imaging and analysis to guide nutrient application will reduce average input but increase crop yield, in particular for high production areas, typically leading to a higher net return for the operation. For low production areas, the yields may remain the same but be associated with a significant reduction in fertilizer use.

Technology

Readiness/commercialization stage

Analytics platforms which translate spatiotemporal information into photogrammetry and other prescriptions have existed for several decades through government organizations. However, it has only been in the past ten years that private organizations have launched their own constellations of satellites which have allowed the option of private prescriptions for the general market.

The sophistication of the technology is increasing such that more information will become available in relatively short periods of time. For example, the application of topography analysis, combined with hyperspectral imaging allows for multiple layer mapping of farms and the diagnosis of either nutrient insufficiency or excess. This will lead to management decisions which should positively impact the choice of which crop to grow, the fertilization protocols, and the efficiency of production while at the same time optimizing environmental parameters.

General risks/uncertainties associated with the technology

Technology risk lays within the method of data gathering. Dependent on the prescription needed, a minimum number of 'passes' are required by a satellite or UAV to feed these analytics systems the information needed to provide the customer their reading. The time between passes continues to be one of the largest risks, as weather events or pathogen spread could occur in between passes, thus rendering the current prescription or topographical reads unrealistic.

The costs associated with geospatial analytics do not allow them to be used by smaller operations easily. These operations have much more difficulty in justifying the applications of the technologies for this reason. The ROI is perceived to be insufficient.

Environmental Benefits

Air, water, land

By use of geospatial imagery data, innovative analytics platforms have the capabilities to map the topography of a plot of land and prime it for agricultural use. These prescriptions can in turn be fed into variable rate seeders, fertilizer systems, and sprayers, allowing for precision seeding and using land to its full potential. This should allow for more uniform crop stands and elevated yield.

Nutrients, yield, plant health

Understanding the metabolic conditions of the plant through gas exchange (CO_2 and O_2 sensing) provides an indication of the vigour of the plant. Healthy plants are more efficient and grow faster. This knowledge then can be applied to address challenges of poor plant health status.

With the data provided from various hyperspectral cameras on drone and satellites, plant health can be measured and processed both non-invasively and objectively. Novel data platforms are able to take geospatial data and predict pathogen spread and determine plant stress in a precise manner leading to precision spraying of pesticide and herbicide. This differs from the traditional method of agronomist's crop scouting and manually checking for disease resulting in the recommendation of blanket spraying and seeding.

Other

Geospatial analytics systems remain quite useful in mapping current and future fluctuations of precipitation, temperature, crop outputs, and more. Further, these systems analyze soil data in combination with historical farming practices to determine the best crops to plant, where they should be planted (topographical), and how to best maintain soil nutrition levels to best benefit the plants.

Commercial Success

Market info

Increasing climate change across the world has created the need for geospatial imagery analytics for evaluating dynamic effects. According to Transparency Market Research 2018, the global geospatial imagery analytics market was valued at $ 4,567 million USD (approximately $5,937 million CAD) in 2016 and is expected to expand at a CAGR of 7% from 2018 to 2026 to reach $ 8,951 million USD (approximately $11,637 million CAD) by the end of the forecasted period. Specifically, the climate change modeling segment of geospatial analytics is expected to register a CAGR of 31% from 2017 to 2024. Video-based solutions are an emerging trend due to a demand for location-based information and increase in smartphone proliferation.

General barriers

The largest technological barrier for the agricultural geospatial analytics sector is access to large, accurate datasets. The competitiveness of an analytics company in this sector remains in their ability to provide frequent prescriptions on large geographical areas. While this barrier speaks to data processing capabilities, it also focuses on the capabilities of the UAVs and satellites from where the platform sources its information. For companies that have multiple satellite rates and dense satellite coverage, this barrier does not exist.

Competitiveness and alternatives

Growing competitiveness in the agricultural geospatial analytics sector exists due to the increasing number of start-up and analytics platforms licensing raw data from existing satellite constellations. The ability to purchase data as a subscription model from a third party has resulted in a surge of geospatial analytic processing companies. Additionally, with increased artificial intelligence and big data, data analysis platforms are also increasing in prevalence. The global geospatial imagery analytics market comprises a large number of multinational companies that offer a range of comprehensive services and solutions to end-users.

Relevance to BC Farming Sector

Market potential in BC

The size and distribution of agricultural production land in BC is determined by the mountainous terrain. The ability of geospatial technologies to identify and map individual farms is paramount to understanding the technology needs for effective farm operations. Some US geospatial analytics companies are currently active in BC, but to date have only worked for some specialty crops. Geo-imaging can be more financially beneficial than sensors for small farms in BC.

Satellite imaging and high-altitude drone technologies and associated analytics would likely have good application in large scale farming operation areas such as the Peace River District and Williams Lake. Lower altitude drone technologies and associated analytics would have use in the Okanagan and Fraser Valleys where farm size is smaller, but land is highly productive and subject to significant management. Additionally, the Fraser Valley is under significant urban pressure to optimize the use of resources and minimize the environmental footprint of farming operations. Use of geospatial analytics can increase the efficiency of production thereby increasing economic stability of the operations and maintaining the sustainability of agriculture production in highly confined areas.

BC specific risks/uncertainties associated with the technology

One potential reason that geo-imaging and analysis is not popularly used in BC is because of the diversity of crop types and plot sizes. Smaller farms likely have greater difficulty paying for this type of service.

Barriers/challenges specific to BC

For smaller farms in BC, the cost associated with geospatial analytics is likely too high and therefore prohibitive for large scale deployment.

Application Programming Interface and Data Analytics

Introduction to Technology Group

Application programming interface (API) is a platform for sharing information/data between multiple software and hardware applications. Agricultural data sources and formats are very diverse, including, for example, data from scouts, aerial imagery, field history, weather forecasting, soil testing, machinery data, etc. APIs allow data to be connected and shared between programs, regardless of source or format. This allows farmers to continue to operate their equipment and software and work with their current service providers, rather than needing to source all equipment and programming from one manufacturer or service provider. Agronomy programs and maps are typically connected through APIs, but other farming systems such as accounting, inventory, etc. can also be connected through the API. For even further coordination, some APIs are open source (e.g., ADAPT[38] and AGCO AgCommand API[39]), enabling open collaboration on data management. In terms of what the farmer sees, all data is typically accessed through one web-based user interface and/or app. Figure 12 shows examples of API platform interfaces used for precision agriculture.

[38] AgGateway. *Adapt: AG Data Application Programming Toolkit.* Retrieved from https://adaptframework.org/
[39] *AGCO Opens AgCommand API to Third-Party Developers*. (2015). Retrieved from https://www.realagriculture.com/2015/08/agco-opens-agcommand-api-to-third-party-developers/

Figure 12 Examples of API platforms used for precision agriculture[40]

Data analytics refers to the analysis of historical, current, and future data to help farmers make real-time and predictive decisions, including development of prescriptive maps.[41] Using data and analytics to improve agronomic opportunities, such as fertilizer timing and rates, requires high quality datasets, as well as in-field validation of the results.[42] In terms of nutrient management, optimizing fertilization requires continuous and complex analysis of large, dynamic data sets, such as soil properties, water infiltration, soil testing, soil and plant nutrient content, nutrient uptake rates, crop yield maps, temperature, precipitation, etc. This is the type of data required, for instance, to analyze and develop prescriptive maps. In terms of real-time data analysis, this allows farmers to make decisions on an ad hoc basis, as situations and events require. For example, a rain event might change the timing of fertilizer application, or satellite imagery data could reveal a nutrient deficiency problem in a specific area of the field that requires a change to the fertilizer application plan. Predictive data analytics uses historical and real-time data, together with statistical models and algorithms to predict future events, enabling the farmer to make informed decisions (e.g., on nitrogen application) and manage risks (e.g., nitrogen leaching).[43]

[40] Image sources: (a) Climate Fieldview, by Climate Corporation https://climate.com/features/data-visualization; (b) FarmCommand, by Farmers Edge Inc. https://www.farmersedge.ca/; (c) AgCommand, by AGCO https://www.fusesmartfarming.com/products/agcommand/; (d) AgDNA https://www.precisionfarmingdealer.com/articles/3025-agdna-unveils-pixel-profit-analysis-tool.
[41] Prescriptive maps can be used for nutrient management and are fed into variable rate technologies for application.
[42] Speck, S. (2018). *The Power of Predictive Analytics in Agriculture*. Retrieved from https://www.precisionag.com/systems-management/data/the-power-of-predictive-analytics-in-agriculture/
[43] Smart Fertilizer Management. Big data analytics and fertilizer management. Retrieved from https://www.smart-fertilizer.com/articles/Digital-ag-and-big-data

Costs

CAPEX, OPEX, ROI as available

For APIs, the cost for growers is typically the cost of web-based annual subscription fees. Hardware may be required for some companies to collect and upload data. For example, Climate FieldView uses hardware, priced at $300 USD (approximately $390 CAD).

For annual operation of APIs and data analytics platforms, costs will vary depending on the product and level of service. For instance, Climate FieldView Pro's nitrogen management platform (available only in the US) costs $1 USD (approximately $1.30 CAD)/acre plus an annual subscription fee of $1,000 USD (approximately $1,300 CAD).[44] Annual costs range from $3,000 to $5,000 USD (approximately $3,900 to $6,500 CAD) for other simple data analytics platforms (i.e., not including agronomic insights), depending on the level of support the dealer or service company provides. For more advanced analytics, such as agronomic insights, costs can range from $3-5/acre CAD. Some full-service companies only offer packages, which include different types of data analytics, in addition to the API. For example, Farmers Edge provides packages at different prices per acre. Examples include API + data collection and zone-based soil sampling + support + variable rate prescriptions = $6 CAD/acre; whereas API + data collection and composite soil sampling + support + flat rate prescriptions = $3.50 CAD/acre. Another example of costs for full service companies was approximately $10,000 CAD/year (up to 2,000 acres or $5 CAD/acre for smaller farms) plus the cost of soil sampling. This service covered both data analytics and geo-imagery processing.

In terms of ROI, there have not been many studies conducted. However, the commentary on ROI of unbiased data analytics tools is positive.[45] Environmental Defense Fund's Nutrient Star program has tested two nutrient management tools (Adapt-N and Climate FieldView). Tests are conducted for yield and nitrogen use efficiency against the best growers. The results varied from positive to negative, depending on location and year.[46] Additional independent studies against typical growers resulted in positive ROI (approximately $12 USD, or approximately $15.60 CAD/acre), as there is more opportunity for improvement (compared to data analytics against the best growers).

Technology

Readiness/commercialization stage

Data analytics platforms and APIs are commercially available.

General risks/uncertainties associated with the technology

One major concern for farmers is that to date, full service companies tend to own the farm data. They do not make the raw data available to the farmers, which means that the farmer cannot use this data with other software, hardware, technologies, companies, etc. It is not the trend to allow farmers to own their raw data. There are exceptions to this though, as data ownership becomes more of an issue and barrier to adoption (e.g., Farmobile, AgDNA, etc.).

[44] Note these were the costs provided during the interview on October 30, 2018. Refer to the Climate FieldView website for current costs.
[45] Turner, P. (2017). *Can big-data deliver big-returns for agriculture?* Towards Data Science. Retrieved from https://towardsdatascience.com/can-big-data-deliver-big-returns-for-agriculture-8800d31440a
[46] NutrientStar http://nutrientstar.org/tool-finder/

Specific to data analytics around nitrogen management, changing how nitrogen is used on farms is a big risk, as it is critical to crop yield. Without scientific, independent data, this is not a decision that will be taken easily by most growers (i.e., do not want to rely on the marketing materials alone of the various data analytics companies and products).[47]

Environmental Benefits

Air, water, land

Not directly applicable to APIs and data analytics.

Nutrients, yield, plant health

Not directly applicable to APIs and data analytics.

Other

API and data analytics products are able to pull data from growers and link any layer of data (e.g., soil data, scouting, harvest data, protein content, etc.), in any raw data format, into one platform. As a result, data management is significantly simplified for the farmer, freeing up time to focus on other aspects of the business. Some products go further (e.g., AgDNA's Pixel Profit) and provide a profitability analysis (profits, ROI) on a per acre basis, assisting farmers to maximise farm potential. Benefits of APIs to farmers include ease of use, use of existing data and sources, simplifying data access, and streamlining the entire farming system (e.g., operational management, financial predictions, record keeping, activity tracking, etc.). As an example, one user of an API moved two full time employees from managing record keeping to other projects after implementing the API as the human record keeping was no longer required. With APIs, all the information is collected automatically and quickly.

Commercial Success

Market info

Although API has been around for a long time, use of APIs in the agriculture industry is relatively new (only a few years old). However, in this short time, APIs have become commonplace. Within the industry, the ability to integrate data is now expected.[48] The use of data analytics tools has potential in Canada, however, the big data analytics companies have mostly been focused on the US to date. This is because of the level of effort required to develop and validate data analytics tools, which are region specific. For instance, the nitrogen loss pathway is very complex, and a huge amount of data and engineering is required to develop, tune, and validate a nitrogen management tool. As a result, data analytics companies have focused their efforts where they have the most acreage (in terms of customers), investment, and local support.

General barriers

Based on a survey of growers in North America, 84% of respondents found it moderately to very difficult to compile and analyze field operations data from multiple sources.[49] These results illustrate both the need

[47] Environmental Defense Fund. *This new approach to farming is transforming agriculture while protecting the environment*. Retrieved from https://www.edf.org/ecosystems/sustainable-agriculture/precision-agriculture
[48] Raven Applied Technology. *Technology once virtually unknown in the ag industry is becoming mainstream.* PrecisionAg. Retrieved from https://www.precisionag.com/sponsor/raven/why-api/
[49] AgGateway. *Adapt: AG Data Application Programming Toolkit.* Retrieved from https://adaptframework.org/

and opportunity for APIs and data analytics tools in the agriculture sector. However, for APIs and data analytics technologies to be readily adopted, the technologies/platforms must be easy to use, add real value, and be easily integrated into existing equipment, programs (e.g., accept multiple data formats), and daily operations.[50] To increase the likelihood of adoption, these products, particularly the user interfaces (e.g., decision support dashboards), need to be scoped and tested by farmers. The systems need data to be collected and displayed in a clean, simple, standardized, and consistent manner. To be useful, they would also require full data integration and an actionable dashboard. Moreover, the platforms should capture data changes over time, and data must be compatible with old and new machinery. Missing any of these elements could lead to a barrier in adoption.

Another potential barrier to adoption in Canada is a lack of local support. A number of the APIs available on the market today were developed outside of Canada. However, APIs, are best deployed on a local level. To date, limited local dealers and sales support has resulted in limited focus on the Canadian market. Some API and data analytics tools prefer to work with dealers who are already dedicated to precision agriculture, such as John Deere. Without the expertise at the dealer level, deploying APIs and data analytics tools can be more of a challenge.

As noted, data availability can also be a barrier to development of data analytics tools. For instance, high resolution, publicly available data and economic models are required to develop and validate certain models (e.g., nitrogen management which is a complex and region-specific process).

Competitiveness and alternatives

API software companies have a marketing struggle to get growers to understand the value of their products. There are a number of API and data analytics tools on the market, all offering slightly varying services, particularly with respect to data analytics. Some companies offer data analytics for only one specific area of farm management, such as nitrogen management. As an emerging industry, there are a range of companies entering the market, from large scale original equipment manufacturers (OEMs) to start-ups.

Relevance to BC Farming Sector

Market potential in BC

The use of data analytics is particularly relevant to those areas that have confined agricultural production (e.g., Fraser Valley, Okanagan Valley) where high value crops rely on high nutrient application, water, and intense management. Without significant support, the volume and types of data will provide a challenge to growers to adopt these technologies.

BC specific risks/uncertainties associated with the technology

As is the case with all technologies, the perceived ROI is a risk. Growers will consider whether they have enough information about the technology to make a decision and whether there would be enough of an impact to warrant the investment.

[50] Smart Fertilizer Management. Big data analytics and fertilizer management. Retrieved from https://www.smart-fertilizer.com/articles/Digital-ag-and-big-data

Barriers/challenges specific to BC

To date, development of data analytics tools (especially predictive analytics) specific to BC may be a barrier. Existing local support may be an initial barrier for adoption of APIs. In terms of operating these types of technologies however, there are no technical barriers for deployment in BC, as broadband is reasonably available. In areas without coverage, these types of technologies can typically be used offline for field work. Data analytics tools and APIs are completely web-based, with all data stored in the cloud. Growers can therefore go online to get access to the data where connectivity is available (i.e., if it is not available on the field itself).

Variable Rate Technologies

Introduction to Technology Group

Nutrient variable rate technologies (VRT) allow the right product to be used at the right rate in the right place at the right time. Variable rate technologies consist of hardware installed on the machinery and software to control it. There are two types of VRT: map-based and sensor-based.

Map-based VRT uses previously developed nutrient prescription maps (planned application rates) that are input to the VRT system in the file format applicable to the machinery. This enables only the required amount of nutrients to be applied to each pre-defined section of the field (production or management zones). The maps are developed using a combination of other precision agriculture technologies, such as drones, satellites, soil sensors/sampling, yield monitors, etc. The map is used along with GPS on the machine to vary the rate of application across the farm.[51] Figure 13 illustrates a typical VRT map-based process.

[51] Grisso, R. et al. (2011). *Precision farming tools: Variable-rate application*. (Publication 442-505). Virginia Cooperative Extension. Retrieved from https://www.researchgate.net/publication/309121121_Precision_farming_tools_Variable-rate_application

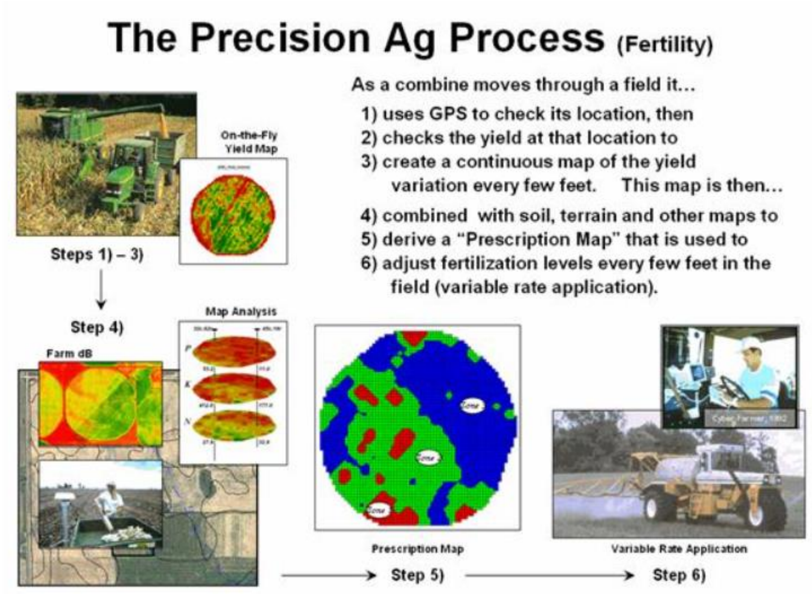

Figure 13 Application of VRT in nutrient management[52]

Sensor-based VRT operates in real-time, where nutrient application rates are adjusted based on data collected and analyzed through on-board sensors (hardware), such as optical indices and soil apparent electrical conductivity and software. Nutrient input needs are calculated on the go and the information is transferred to the application controller. No GPS is required; however, if sensor data is recorded along with GPS data, then the real-time information can be used to create prescription maps for future operations.[53]

In both cases, variable rate control tools are often integrated with guidance system products (e.g., auto-guide, autosteering technologies), which ensures nutrient application without overlap and skips. The trend is toward guidance system products being a fundamental component of complete VRT systems.

Costs

CAPEX, OPEX, ROI as available

Variable rate technology hardware is typically included in new machinery. Many farmers already have equipment that is capable of VRT, however they are not using it. If the VRT hardware is put to use, the farmer would face additional capital and operating costs. Costs may include software and services related to VRT, inputs for map-based VRT (i.e., prescription maps), or sensors to operate real-time VRT. Costs for these are discussed in their respective technology groups. When purchasing new, costs for a complete system (e.g., guidance system, VRT hardware, software, etc.) are approximately $20,000 USD (approximately $26,000 CAD) (±20%). Agronomists who offer services around VRT typically charge

[52] Image source: Berry, J.K. (2006). Beyond Mapping III, Topic 10 – Spatial Data Mining. Spatial Data Mining "Down on the Farm." Posted by GeoWorld. In Beyond Mapping. Retrieved from . http://www.innovativegis.com/basis/BeyondMappingSeries/BeyondMapping_III/Topic10/BM_III_T10.pdf
[53] Grisso, R. et al. (2011). *Precision farming tools: Variable-rate application*. (Publication 442-505). Virginia Cooperative Extension. Retrieved from https://www.researchgate.net/publication/309121121_Precision_farming_tools_Variable-rate_application

between $5-15 CAD/acre. The costs vary depending on the technologies that are used, the amount of soil sampling required, type of analysis required, and level of VRT service provided.[54]

The payback period for complete VRT systems is fast, at approximately two and a half years. Economic benefits typically come from increasing yield, reducing input costs, and managing risks. Farms can focus inputs in management zones that provide the highest return, while reducing inputs in zones with lower productivity or reduced need. Specific financial benefits depend on the variability in soil type, landscape, inherent nutrient reserves, and previous management practices on the farm. There is potential for a higher ROI if the field contains significant variability of soil types in a field. The timing strategy (e.g., all up-front, or split applications) and whether VRT is used both times will also affect the financial benefit.

A number of studies have been done that provide the following range of results:

- Government of Australia study: Range of benefit over flat rate fertilizer varied from $10-30 AUD/ha (approximately ~$3.80-11.40 CAD/acre)[55] and up to $100 AUD/ha (approximately ~$38 CAD/acre).[56]
- University of Illinois study: Farmers save approximately $5 USD (approximately $6.50 CAD)/acre) using VRT for nitrogen fertilization.[57]
- Virginia Tech study: Returns varied widely by crop type, input, and technology. Example, average return on VRT for nitrogen in sugar beet was $74 USD (approximately $96.20 CAD)/acre) and average return on VRT for lime was $3.46-5.07 (approximately $4.50-6.59 CAD)/acre).[58]

Technology

Readiness/commercialization stage

Variable rate technologies are fully commercially available from a number of suppliers.

General risks/uncertainties associated with the technology

Even though the potential financial and associated environmental and risk management benefits appear positive and applicable to most sectors of the industry, there is considerable risk and uncertainty around ROI, as the results are completely land dependent.

Environmental Benefits

Air, water, land

There is limited data on specific GHG emissions reductions due to VRT. However, GHG emissions reduction would result from reducing the total amount of fertilizer or manure applied, including N_2O emissions (from decreased fertilizer application), CO_2 emissions from fuel reduction (from timely fertilization and reduced weight of the hopper) and CH_4 emissions (from decreased manure use). More research has to been done on N_2O emissions reductions (from N fertilizer production and use). However, it is known that

[54] McKenzie, R.H. (2014). *Variable rate fertilizer application – a common sense approach*. Top Crop Manager. Retrieved from https://www.topcropmanager.com/variable-rate-fertilizer-application-a-common-sense-approach-14852/
[55] Conversion assumes 1 AUD = 0.95 CAD.
[56] Government of Australia, Natural Resources, SA Murray-Darling Basin. *Variable Rate Technology Farming*. Retrieved from https://data.environment.sa.gov.au/Content/Publications/Variable%20Rate%20Technology%20(VRT)%20Farming%20v2.pdf
[57] Igor, I. (2018). Variable Rate Application in Precision Agriculture. Medium. Retrieved from https://medium.com/remote-sensing-in-agriculture/variable-rate-application-in-precision-agriculture-70a8b2be871d
[58] Grisso, R. et al. (2011). *Precision farming tools: Variable-rate application*. (Publication 442-505). Virginia Cooperative Extension. Retrieved from https://www.researchgate.net/publication/309121121_Precision_farming_tools_Variable-rate_application

the relationship of N_2O emissions to nitrogen application rate increases proportionally with the application rate.

Various studies have been conducted with different results. For example, a 2009 study showed a 5-10% GHG emissions reduction for mineral fertilizer VRT. A 2004 study saw N_2O emissions reductions of 1.25% for nitrogen inputs. A 2003 study found a 34% reduction in N_2O emissions in low-yield areas. One VRT company states an increase in nitrogen use efficiency can reduce the carbon footprint by 10-30%. The nitrogen cycle is extremely complex, depending on a large number of variables. As a result, VRT for nitrogen fertilizer combined with irrigation scheduling and precipitation prediction can reduce associated GHGs even more.

In terms of environmental benefits to water and land, more precise and potentially decreased application of fertilizer and manure would result in reduced nutrient runoff, therefore having a positive impact on nearby water sources and land. In addition, fewer passes for manure or fertilizer application means less soil compaction and positive impacts on the land.

Nutrients, yield, plant health

There is a good potential for increased yield, particularly in low productivity areas, due to more efficient fertilization based on actual crop needs and variability of soil. For instance, studies conducted for the N Sensor (a nitrogen sensor used for sensor based VRT) showed cereal yields increased by 3.5% and oilseed yields increased by 3.9%. In addition, nitrogen savings of up to 14% were realized. Another study, by Echelon/Nutrien Ag Solutions (data analytics used to input into map based VRT) found an average yield increase of 10.8% in canola, 5.9% in wheat, and 6.4% in barley. They saw a 10% increase in yield for high production areas, but no change in yield for low production areas. However, in low production areas, there was a 20-30% reduction in fertilizer use. Overall, across the whole field, there is a 1.5% yield increase, which aligns with a USDA study. The Government of Australia VRT study found that VRT was more beneficial in systems with intensive cereal rotations and less so in fields following a legume crop. That study also found that using VRT on sandier soils improved yields (with higher upfront nitrogen application), but not in an economically efficient way. Whereas reduced fertilizer inputs in heavy loams and shallow stony soils gave positive results.

Regarding plant health, it is generally accepted that the less you do to a plant, the healthier the plant is from a holistic perspective. The less inputs applied, the healthier the environment and products, and the happier the final consumers.

Other

Variable rate technology offers real benefits to farmers during operations. Use of autonomous machinery (e.g., autosteer and VRT) is less physically and mentally demanding for farmers. This could allow for safer operation (i.e., less driver fatigue), particularly in waning daylight conditions or during long days. In addition, with automation, the farmer/owner may feel more comfortable having an employee conduct the nutrient application operations, while they remotely view the tractor movements, fertilizer application, etc. in real-time to monitor if the work is being done correctly.

Commercial Success

Market info

In 2016, the VRT market was valued at $1.31 billion USD (approximately $1.7 billion CAD). It was projected to grow at a compound annual growth rate of 9.65% from 2017 to 2022, reaching $2.24 billion USD (approximately $2.91 billion CAD).[59]

A recent USDA report[60] estimated that 20% of growers in the US have adopted VRT. Ten years ago, the adoption rate was half of this at 10%. In Canada, 15% use some sort of VRT, but the data is not entirely clear, as the survey question was related to use of computers, and not specific to VRT.

General barriers

Typically farms with high margins have higher rates of adoption for precision agriculture technologies. They are more willing and able to adopt high cost technologies and take more risks.[61] Demonstrating a clear payback to using VRT systems is a barrier for low-risk farm operations. Cost is a barrier when considering the entire VRT system. This includes the inputs (e.g., acquiring the data layers necessary to generate a prescription map or acquiring the on-board sensors), processing (e.g., software and analytics), and outputs (e.g., the hardware that controls the machinery).

Many farmers have the capacity (i.e., their machinery already has VRT capabilities), but they need help with the process, inputs, technologies, machinery, data analysis, etc.[62] Complete VRT systems can be very complex, requiring in-depth knowledge of both agronomics and technologies. Providing farmers with soil and agronomy support as well as technical data management assistance for their machinery can rapidly increase adoption of VRT. Using service providers is another way to address both the knowledge/complexity barrier, as well as the cost barrier. A "turnkey" solution approach helps to entice growers to use the service.

The equipment itself can be another barrier. Equipment systems don't always talk to each other (i.e., different OEMs, etc. do not integrate well with others). Tools must become interoperable across different manufacturer datasets no matter the equipment type, crop type, etc. Also, conventionally, the decision to buy a machine is based on key features other than technology, but for VRT farming, technology needs to be a primary consideration. Also, if farming machinery is purchased second hand, the technical support for the technology may no longer be available, as technologies are continuously evolving.

Another barrier related to VRT systems (and precision agriculture in general) is inadequate internet or cell coverage. Rural broadband is typically needed to deploy precision agriculture products.

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[59] *Variable Rate Technology (VRT) Market by Type, Offering, Crop Type (Cereals & Grains, Oilseeds & Pulses, and Fruits & Vegetables), Application Method (Map-based and Sensor-based), Farm Size (Large, Mid-sized, Small), and Region – Global Forecast to 2022*. Markets and Markets. (2017). Retrieved from https://www.marketsandmarkets.com/Market-Reports/variable-rate-technology-market-178591689.html

[60] Schimmelpfennig, D. (2016). *Farm Profits and Adoption of Precision Agriculture* (Economic Research Report Number 217). United States Department of Agriculture, Economic Research Service. Retrieved from https://www.ers.usda.gov/webdocs/publications/80326/err-217.pdf?v=0

[61] Farming: There's an App for That. National Geographic. (2018). Retrieved from https://www.nationalgeographic.com/environment/future-of-food/food-future-precision-agriculture/

[62] Government of Australia, Natural Resources, SA Murray-Darling Basin. *Variable Rate Technology Farming*. Retrieved from https://data.environment.sa.gov.au/Content/Publications/Variable%20Rate%20Technology%20(VRT)%20Farming%20v2.pdf

Competitiveness and alternatives

The tools for VRT combine hardware, software, and operational techniques. The usefulness of each tool varies from farm to farm and field to field and therefore the best information for VRT management should be gathered at the field level (i.e., within the boundaries of each field). The present VRT systems are not designed to completely replace industry professionals and farmers in management decisions but provide information and tools to improve input use-efficiency. There are a number of major farm equipment OEMs that offer VRT hardware and software.

Relevance to BC Farming Sector

Market potential in BC

Variable rate technology is most applicable to annual crops rather than perennial crops. For instance, using VRT on an apple orchard will not reap the same benefits as using VRT on a wheat crop. Variable rate technology products are often focused on row crops (e.g., wheat, corn, and canola).

Variable rate technology works on any farm above 100 to 200 acres. However, for smaller farms in dense agricultural areas, VRT will have limited value. There would be more utility for VRT in the larger operations found in Williams Lake and Peace River districts. In addition, large farms can typically absorb the costs of VRT more easily.

BC specific risks/uncertainties associated with the technology

Variable rate technology is most beneficial when a farm has highly variable soil types across the farm[63] (e.g., Fraser Valley and Okanagan Valley topographies with high value crops). Fields with rolling topography have good potential for using VRT, as this generally indicates soil variability.[64]

Barriers/challenges specific to BC

Capital costs and demonstrating a clear payback to using VRT systems is a barrier for low-risk farm operations. Smaller farms (e.g., berry farms) with higher plant densities would have difficulty using VRT in a cost-effective manner. Only farms with significant acreage would benefit from using VRT (four in ten farms in BC are considered small, and these are not likely to take advantage of VRT).

In addition, a lack of independent soil and agronomy support for farmers is a barrier in BC. Rural broadband may also be a barrier in certain areas of the province (e.g., mountainous areas). BC does have a broadband satellite initiative, but 70% of rural communities are currently without broadband connectivity.[65]

[63] Government of Australia, Natural Resources, SA Murray-Darling Basin. *Variable Rate Technology Farming*. Retrieved from https://data.environment.sa.gov.au/Content/Publications/Variable%20Rate%20Technology%20(VRT)%20Farming%20v2.pdf
[64] McKenzie, R.H. (2014). *Variable rate fertilizer application – a common sense approach*. Top Crop Manager. Retrieved from https://www.topcropmanager.com/variable-rate-fertilizer-application-a-common-sense-approach-14852/
[65] Zeidler, S. (2018). *B.C. rural and Indigenous communities to get faster internet connections*. Global New. Retrieved from https://globalnews.ca/news/4107009/b-c-rural-indigenous-communities-faster-internet/

Guidance and Autosteer

Introduction to Technology Group

The automated steering system is a GPS guidance system used to steer a moving vehicle (e.g., tractor, baler, combine, or sprayers) automatically. It can be integrated directly into a vehicle's hydraulics, allowing the farmers to obtain clear access to cab controls. As an example, Figure 14 shows the inside view of the cab of the AGCO Fendt 900 Vario System.

Figure 14 Cab of the Fendt 900 Vario System[66]

GPS signals are received and processed from GPS satellites and "signal correction" sources, such as the differential global positioning system (DGPS) or real-time kinematic (RTK) local base station. These signals are combined to generate the true location of the vehicle, which is used by the navigation system to control the automated steering. Both DGPS and RTK are methods to correct errors of signals sent from satellites. RTK has higher data accuracy (centimeter level) than DGPS (submeter level).

The only agbot identified for nutrient management was the Rowbot (Figure 15).[67] It is a new robotic technology owned by a Minnesota start-up company to deploy an autonomous robot that rolls between row crops spraying fertilizers. This is accomplished with the integration of both GPS and LIDAR technologies. With GPS, the machine knows when it has reached the end of the field. With LIDAR, or laser-scanning, the machine can stay between rows of mature cornstalks without hitting them.[68]

[66] Image source: Fendt – a worldwide brand of AGCO https://www.fendt.com/int/11916.html
[67] Rowbot https://www.rowbot.com/
[68] Talbot, D. (2014). A Nimble-Wheeled Farm Robot Goes to Work in Minnesota. MIT Technology Review. Retrieved from https://www.technologyreview.com/s/530526/a-nimble-wheeled-farm-robot-goes-to-work-in-minnesota/

Figure 15 Rowbot[69]

Costs

CAPEX, OPEX, ROI as available

Most of the automated steering systems (without the RTK base) range between $10,000 and $20,000 USD (approximately $13,000 – 26,000 CAD), depending on the level of accuracy of the system – the more accurate the more expensive. Systems with the RTK base stations in most cases are higher than $30,000 USD (approximately $39,000 CAD).

Taking AGCO's Auto-Guide as an example,[70] the cost of the most accurate system, i.e., the RTK system, is $30,000+ USD (or approximately $39,000+ CAD, including the cost of the base station), which triples the cost of the basic submeter system ($10,000 USD, or approximately $13,000 CAD). The decimeter meter system, which has an intermediate accuracy level between the submeter and RTK systems, is $15,000 USD (approximately $19,500 CAD). As another example, the cost of Trimble's AgGPS Autopilot DGPS system is $10,995 USD (approximately $14,294 CAD)[71] and the cost is $20,000 USD (approximately $26,000 CAD) for the AgGPS Autopilot RTK network automated steering system.[72]

In general, the cost of agbots is still high. Nevertheless, with the advancement of autonomous technologies, agbots will be more economically feasible for farmers. For example, the cost of a robot is comparative to human labour costs in some applications, such as lettuce weeding, according to studies done by Lux Research. As with other technologies, large farms can absorb the capital costs of agbots more readily than smaller farms.

In terms of operating costs, in most cases, the higher-accuracy systems of automated vehicles and steering systems require an annual subscription for a satellite GPS signal or an RTK correction cost. Depending on

[69] Image source: Carnegie Robotics Ag Rowbot Featured in MIT Tech Review https://carnegierobotics.com/news/2014/9/9/carnegie-robotics-ag-rowbot-featured-in-mit-tech-review

[70] Automated Steering Systems. Farm Industry News. (2007), Retrieved from https://www.farmindustrynews.com/automated-steering-systems

[71] Trimble. (2005). *Payback Factsheet: AgGPS Autopilot DGPS system*. Retrieved from http://trl.trimble.com/docushare/dsweb/Get/Document-267215/022503-139_Payback_Factsheet_Autopilot_DGPS_HP_XP_Broadacre_1005_lr.pdf.

[72] Trimble. (2005). Payback Factsheet: AgGPS Autopilot RTK network system. Retrieved from http://trl.trimble.com/docushare/dsweb/Get/Document-267214/022503-138_Payback_Factsheet_Autopilot_RTKNet_RTKBS_Broadacre_1005_lr.pdf

the specific technology/company, the annual cost typically falls in the $800-2,000 USD (approximately $1,040-2,600 CAD) range.[73]

Rowbot was used in summer 2014 to fertilize 50 acres of corn at a charge of $10 USD (approximately $13 CAD) per acre (plus the cost of fertilizer). Rowbot can reduce unnecessary use of nutrients, therefore reducing the overall cost of fertilizers for farmers.

Based on studies by Trimble, the payback period of the DGPS system is 13.5 months for a 1,000 broadacre application. As for the RTK system, it is 18.9 months. Use of the autopilot system, results in significantly reduced costs of labour, inputs, and fuel. For example, the standard fuel cost of a 1,000 broadacre application is $4,330 USD (approximately $5,629 CAD). This decreases to $3,062 USD (approximately $3,981 CAD) with the autopilot system, representing a 29% reduction. The overall cost saving is $0.91 USD (approximately $1.18 CAD)/acre for the RTK system, and $0.72 USD (approximately $0.94 CAD)/acre for the DGPS system.

Table 4 Payback Summary of Trimble's AgGPS Autopilot Systems

	AgGPS Autopilot DGPS system	**AgGPS Autopilot RTK system**		
1,000 acres application	Broad application	Broad application	Corn and Soybean[74]	High value crops and cotton[75]
- System cost	$10,995 USD ($ 14,294 CAD)	$20,000 USD ($26,000 CAD)	$20,000 USD ($26,000 CAD)	$20,000 USD ($26,000 CAD)
- Payback period	13.5 months	18.9 months	10.9 months	1.7 months
- Labour cost saving	$699 USD ($909 CAD)	$717 USD ($932 CAD)	$828 USD ($1,076 CAD)	$1,491 USD ($1,938 CAD)
- Input cost saving	$1,697 USD ($2,206 CAD)	$2,404 USD ($3,125 CAD)	$4,506 USD ($5,858 CAD)	$108,378 USD ($140,891 CAD)
- Fuel cost saving	$1,220 USD ($1,586)	$1,268 USD ($1,648 CAD)	$1,404 USD ($1,825 CAD)	$3,432 USD ($4,462 CAD)

Technology

Readiness/commercialization stage

Automatic steering technologies have been fully commercialized for many years and many brands have their own automatic steering products. The accuracy of these technologies can be as high as sub-1 inch with the RTK technology.

The Rowbot is still at the early commercialization stage. It is operating on $2.5 million USD (approximately $3.3 million CAD) of seed funding. There are current discussions with researchers at the University of Illinois to conduct studies to prove the advantages of its approach. The next step is to deploy multiple Rowbots on

[73] Fulton, J. (2011). *GPS Equipment and Accuracy*. Auburn University. Retrieved from http://www.aces.edu/anr/precisionag/documents/GPS_GNSSBasics.pdf
[74] Trimble. (2005). Payback Factsheet: AgGPS Autopilot RTK network system. Retrieved from http://trl.trimble.com/docushare/dsweb/Get/Document-267214/022503-138_Payback_Factsheet_Autopilot_RTKNet_RTKBS_Broadacre_1005_lr.pdf
[75] Trimble. (2005). Payback Factsheet: AgGPS Autopilot RTK network system. Retrieved from http://trl.trimble.com/docushare/dsweb/Get/Document-267214/022503-138_Payback_Factsheet_Autopilot_RTKNet_RTKBS_Broadacre_1005_lr.pdf

industrial-scale farms, and to add more sensing capacity to the machines. The company is also testing them for planting seed on cornfields for fall crops (cover crops), while the mature corn is still standing.

General risks/uncertainties associated with the technology

Guidance and autosteer systems are risk-free. With "hands-free" steering, autosteer systems allow farmers to reduce fatigue and focus on other farming tasks to improve safety on the farm.

Environmental Benefits

Air, water, land

Most companies have not done specific environmental studies. They are more focused on testing their products and making sure their products work correctly.

For guidance and autosteer systems, GHG emissions can be reduced through reduced use of fossil fuels resulting from improved machinery efficiency, accuracy (reduced overlaps), and productivity (increased speed and labour productivity in acres/hour). Fuel savings, as well as associated GHG and CAC emissions reductions, are typically higher than 20%.

As for Rowbot, it can spray crop fertilizer on corn crops itself, eliminating the need for tractor use and consequently reducing fossil fuel (i.e., diesel) consumption and associated GHG/CAC emissions.

Nutrients, yield, plant health

Not directly applicable to guidance and autosteer technologies.

Other

As with VRT, guidance and autosteer technologies offer real benefits to farmers during operations. Use of autonomous machinery is less physically and mentally demanding for farmers, which could allow for safer operation.

Commercial Success

Market info

Automation is most useful where consumer demand and labour requirements are greatest. The current application of robots in agriculture is mainly at the harvest stage, and some during chemical spraying, fruit picking, and crop monitoring. The application of robots for nutrient application is relatively limited. Autosteer technologies have been fully commercialized and available for many years. Guidance and autosteer technologies are typically focused/used on row crops.

General barriers

The cost of guidance and autosteer systems may be relatively high for small farms. Network coverage is another barrier for technology implementation.

Competitiveness and alternatives

Most large equipment manufacturers have had guidance and autosteer available for their equipment for a number of years. Agbots for nutrient management are in their infancy. There are no commercially available units, and only one (Rowbot) has been identified in the pre-commercialization stage.

Relevance to BC Farming Sector

Market potential in BC

Most of the current guidance and autosteer products are focused on row crops. There is a potential market in Northeastern BC, where canola and wheat grow. Use in small acreage farms is in its infancy but is likely to grow in the future. The development of robotics for these reasons will make these technologies more competitive.

BC specific risks/uncertainties associated with the technology

Cell coverage and communication capacity are required for the technologies. Some rural areas in BC lack the necessary network coverage and internet access capacity for these technologies to operate.

Barriers/challenges specific to BC

Smaller farms in BC may face a cost barrier to these technologies, as they are typically more financially beneficial (e.g., quicker payback) for larger farms.

5. Overarching Barriers to Precision Agriculture Adoption

This section outlines barriers that are specific to the whole "system", that is a complete application of precision agriculture for nutrient management, and not just one specific technology. Technology specific barriers were covered in Section 4. These barriers include:

- **Costs:** High capital costs and uncertainties with respect to ROI given the early stage of precision agriculture technologies in Canada (limited track records).
- **Risk aversion and limited understanding:** The value of data is not fully understood. There is also a lack of desire and/or ability to interpret and apply the multitude of complex data captured through precision agriculture technologies.
- **Aging farmer population:** It is unlikely that there will be a big uptake until there is a generational change. Precision agriculture planning may go against the intuition/decades of experience of the farmer.
- **Technology limitations:** Some technologies are unsuitable for BC farms due to lack of access to wireless coverage, as well as soil and weather conditions (e.g., some technologies will not work with pooled water or snow pack).
- **Integration of hardware and software:** Lack of seamless integration between technologies, equipment, and data.
- **Data ownership issues:** Lack of access for farmers to their own raw data.

A few of the key barriers are further elaborated on below.

Costs

Precision agriculture technologies are costly. Larger farms have higher rates of adoption, as they are able to better absorb and manage the capital and operating costs of precision agriculture technologies. Farm size, yields, and market price all play a role in whether a farmer can invest in precision agriculture, with smaller farms seeing a much longer payback period (e.g., double the time) than larger farms. In addition, according to a USDA report[76], a large stock of existing machinery may have a negative effect on the adoption of precision agriculture technologies. This is possibly due to reduced flexibility in taking on new capital costs and not wanting to have stranded assets (e.g., existing equipment that has not reached end-of-life). For a greater adoption of precision agriculture technologies, costs need to substantially decrease to show a clear benefit to the grower. This may not happen with existing precision agriculture technologies. It may only be new/future technologies that will be able to cost effectively provide precision agriculture services.

Understanding and Age

The success of precision agriculture deployment and adoption depends on the technologies as well as the farmer's ability, knowledge, willingness, and confidence in using the technologies and trusting the outputs. Farmers must be willing to integrate their experience with precision agriculture technologies for optimal results. Many farmers do not want to change methods that have worked for generations, particularly when outputs from precision agriculture technologies may go against the farmers experience or intuition.[77] It is a

[76] Schimmelpfennig, D. (2016). *Farm Profits and Adoption of Precision Agriculture* (Economic Research Report Number 217). United States Department of Agriculture, Economic Research Service. Retrieved from https://www.ers.usda.gov/webdocs/publications/80326/err-217.pdf?v=0
[77] Personal communication with precision agriculture expert.

constant challenge to get farmers to adopt new technologies, especially with continuously evolving technologies.

With respect to precision agriculture technologies, there are clear steps with existing technologies that farmers could be taking, but they are not. Why this is the case and how to solve this problem needs to be addressed moving forward, if BC wants to see a successful adoption of precision agriculture technologies in nutrient management. One consideration is that a farmer's age may impact willingness to adopt new technologies. It is the belief of some that mass adoption will not occur until there is a generational change on the farms.[78] However, as noted earlier, farmers between 35-54 years of age appear to have higher adoption rates than farmers less than 35. This may have to do with less experience, less financial resources, etc.

Technologies and Data

There are a few technical barriers that span the entire precision agriculture system.

Most of the elements of a precision agriculture system require internet and cellular coverage for operation and/or data collection and transfer. According to the Farmer Survey in Western Canada, 52% of the respondents indicated that they are somewhat or very unsatisfied with their internet service and internet speed. Two percent even indicated that they do not have internet coverage. As for cellular coverage and cellular data coverage, 45% indicated they were somewhat or very unsatisfied.[79] As a result, network coverage may be a particular barrier in more remote areas of BC as well where cell coverage is limited.

Data standardization is another big issue. Data collected from various machinery (old and new), technologies, and platforms are in different formats and can therefore not be compiled into one interface to be reviewed, analyzed, and shared freely. In addition, some data platforms are not at all compatible with older machinery. Interoperability is a huge hurdle for the use of precision agriculture technologies. Data aggregation and interpretation may also be a challenge for farmers. Without support, many farmers do not have the ability to understand the data, and how to use the data to make informed decisions on their farming operations.

[78] Personal communication with precision agriculture expert.

[79] Steele, D. (2017). *Analysis of Precision Agriculture, Adoption and Barriers in Western Canada, Producer Survey of Western Canada*. Prepared for Agriculture and Agri-Food Canada. Retrieved from https://www.realagriculture.com/wp-content/uploads/2017/04/Final-Report-Analysis-of-Precision-Agriculture-Adoption-and-Barriers-in-western-Canada-April-2017.pdf

6. Overarching Benefits of Precision Agriculture

While the benefits are difficult to quantify in actual terms for BC farmer operations at present, given their low adoption rate, this section outlines potential environmental and economic benefits in general terms. These are specific to the whole "system," that is a complete application of precision agriculture for nutrient management, and not just one specific technology. Technology-specific benefits were covered in Section 4. These benefits include:

- **GHGs and Air:** GHG emission reductions result from an overall decrease in nutrient application, reduced fuel consumption (and associated emissions) from farm equipment, as well as reduced emissions associated with nutrient manufacturing. Note that there has been limited study of the environmental benefits of specific precision agriculture technologies for nutrient management.
- **Water:** Precision nutrient application (e.g., amount, timing, location) leads to decreased nutrient runoff and resulting water contamination.
- **Soil:** Fewer passes for nutrient application results in decreased soil compaction. Precision nutrient application (e.g., amount, timing, location) leads to decreased nutrient runoff and resulting soil contamination.
- **Plant Health:** Increased yield and improved plant health results from more tailored use of nutrients.
- **Economic:** In general, precision agriculture technologies optimize resource use on the farm. This results in reduced input costs (e.g., fertilizer) and reduced fuel costs through some technologies (e.g., guidance and autosteer and VRT). Other technologies help to reduce the cost of labour (e.g., guidance and autosteer) and manage risks (e.g., VRT). In addition, GPS/GIS technologies increase the operational efficiency of production (e.g., better allocation of equipment, reduction in lab sampling costs, reduction in labour requirements, etc.). Economic benefits of precision agriculture technologies also result from increasing yield.

A few of the key benefits are further elaborated below.

Air, Water, and Land

This scoping study revealed that very few quantitative studies have been done on environmental benefits to air, land, and water for precision agriculture technologies. However, it is widely accepted that the most significant and direct environmental benefit with precision agriculture technologies is that combined, these technologies enable optimization (product, amount, timing, and location) of nutrient inputs (e.g., fertilizers applied to the field), which results in reduced nutrient leaching and runoff, causing less soil and water contamination. Applying less nitrogen-based fertilizers also results in reduced N_2O emissions, which is a significant benefit compared to other farm-related emissions. To a lesser extent, there are also direct CO_2 emissions reductions from reduced application of lime. In addition to the direct benefits, indirectly the application of precision agriculture technologies results in reductions in emissions of GHG emissions and other air contaminants (e.g., CO, SOx, NOx, and particulate matter) as a result of reduced fossil fuel consumption with improved machinery efficiency, accuracy, and productivity.

Using precision agriculture technologies for nutrient management supports the 4R philosophy (right product, right time, right location, right amount). Applying the right amount of seed and fertilizer to grow the most efficient crop will improve efficiency and result in environmental benefits. In addition, by removing low productivity areas which are cut out of the map and turned off, resources don't get wasted.

While there may be local benefits to using precision agriculture technologies for nutrient management, it should be noted that the system of precision agriculture technologies is extremely data intensive. Most data that is being captured, transmitted, and analyzed passes through or is stored in the cloud at one time or another. Cloud computing requires huge amounts of server space and energy. Data centres and server farms are energy intensive facilities, contributing to global GHG emissions. Depending on where they are located, the source of electricity for power and cooling could be anything from coal (e.g., US) to geothermal (e.g., Iceland).

Other Benefits

Precision agriculture improves whole farm management, from operational management to financial predictions. Data collection, analysis, management, and application are automated and streamlined through the use of precision agriculture technologies. Record keeping and activity tracking is easier, which allows farmers to focus their time and energy on other aspects of the farming operation.

7. Conclusions

The global precision agriculture technology market has been steadily growing. The market is expected to grow at a rate of 12.5% over the next four years and in the past five years, venture capital in agriculture technologies has increased 20-fold. In the US, guidance and autosteer segments appear to have the most potential, whereas in Canada, western farmers tend to consider sensors to be the most beneficial. From the nutrient management perspective, nitrogen contamination due to fertilizer overdosing is a big challenge for the agriculture sector. Current global nitrogen use efficiency is only 35-40%, meaning that there is a great opportunity to improve the efficiency through accurate rate and timing control on nutrient applications using precision agriculture technologies.

Key Takeaways

Key takeaways for the BC Ministry of Agriculture to consider when identifying and assessing next steps are listed below.

BC Farm Sector

- Highly concentrated, agriculturally dense regions could greatly benefit from precision agriculture for nutrient management (e.g., data analytics). However, the opportunity for application may be lower than other regions due to smaller farm size, cost, and potential ROI.
- There are fewer barriers facing larger operations with more “prairie-like” production, as well as annual crops, to implementing precision agriculture for nutrient management. Technologies suitable to annual, high acreage row crops include VRT, GPS/GIS, and guidance and autosteer.

Technology Limitations

- There is currently no system to integrate all technologies, data, and applications. Each of the technologies is discrete and therefore a farmer would have to go with a full-service company (e.g., Farmers Edge, Climate Corp) if they wanted to integrate/use a number of precision agriculture technologies together for a complete nutrient management system. It is currently not possible for them to use and integrate multiple technologies on their own.
- There are some companies (e.g., AgDNA) that are working to integrate all different types of data (from different hardware and software technologies) into one platform. These companies may be able to assist BC farmers in bringing together more holistic systems for technology adoption. However, applying this type of data platform in practice still requires analysis and agronomy support to know what it all means and how to use it.
- Even as discrete technologies, they need to be simple to use. Farming is a risk-averse sector. Precision agriculture technologies need to be as easy as possible to implement and operate. Need to make technologies and associated dashboards simple and actionable with no or very little disruption to current farm management systems. This approach will help improve the adoption of new technologies.
- New equipment tends to come equipped with some precision agriculture technologies (e.g., autosteer, VRT), but these technologies are not often being used effectively by BC farmers. There is currently more equipment capacity than actual usage.

Understanding the Benefits

- GHG and air emission reductions result from an overall decrease in nutrient application, reduced fuel consumption (and associated emissions) from farm equipment, as well as reduced emissions associated with nutrient manufacturing. There has been a lot of research on environmental benefits of reducing nutrient application. However, the companies developing and producing precision agriculture technologies for nutrient management are generally not conducting studies specifically for their technologies, it is therefore difficult to determine expected emission reductions by technology.
- Precision nutrient application (e.g., amount, timing, location) leads to decreased nutrient runoff and resulting soil and water contamination. Fewer passes for nutrient application also results in decreased soil compaction.
- Increased yield and improved plant health results from more tailored use of nutrients and real-time monitoring.
- Economic benefits to BC farmers result from optimizing resource use on the farm (e.g., reduced input and fuel costs) and increasing yields. Additional benefits arise from reduced labour costs, better risk management, and increased operational efficiency.

Addressing the Main Barriers

- Behavioural change is required. It will be important to understand what drives farmers to adopt or not adopt precision agriculture technologies. What do farmers in BC need to move ahead with precision agriculture? For example, one main shift for farmers would be making decisions without ROI. For new technologies, robust ROI data is generally not available. In addition, for some technologies, such as VRT, ROI is very land dependent (i.e., varies with each field and farm) and therefore is still an unknown. In addition, there are some regions and types of crops where the prevailing mentality is to maximize yields (and profits) rather than optimizing operations.
- Increased education and awareness are required. The value of data is not fully understood. There is also a lack of desire and/or ability to interpret and apply the multitude of complex data captured through precision agriculture technologies. It is possible that a generational change will be required before a big uptake of precision agriculture technologies exist, as the results of precision agriculture planning may go against the intuition/decades of experience of the farmer.
- Increased and improved service and consulting is required. There needs to be an increase of independent (i.e., not tied to any one product, supplier, etc.) support services and consultants to work with individual farms, depending on crop, existing equipment, budget, etc. to develop the best precision agriculture for nutrient management system on a case by case basis. The trusted professionals will need to have an in-depth understanding of both technologies and agronomy.
- Addressing the data concerns will be required. There needs to be seamless integration between technologies (hardware and software), equipment, and data. In addition, data should be owned by farmers, not the companies that collect the data. This way, farmers can use the data more effectively in a variety of platforms to optimize farm operations. Furthermore, often farmers are protective of their data for competitiveness reasons and having a third-party company own their data could be a barrier to greater adoption in its own right.
- Finally, the high capital costs need to be addressed. Many of the technologies are out of reach for farmers that operate on tight margins. Without incentives, many farmers will not be able to deploy precision agriculture for nutrient management regardless of interest. Currently, the costs for some

technologies (e.g., geo-imaging) only makes financial sense for large producers. It may be that only new technologies, yet to be developed, will become cost effective enough for mass deployment of precision agriculture technologies for nutrient management.

Appendix A: Detailed Project Methodology

The Delphi Group, in partnership with Bioenterprise Corporation, conducted an agriculture clean technology scoping study on behalf of the BC Ministry of Agriculture to better understand the potential for precision agriculture and nutrient management technologies to be deployed in BC.

The project was conducted in four phases:

- Phase 1: Project kick-off and finalize work plan
- Phase 2: Scoping research
- Phase 3: Synthesize and analyze results
- Phase 4: Prepare final report.

Phase 1

A kick-off meeting was held with The Delphi Group, Bioenterprise, and the BC Ministry of Agriculture to agree to a final scope of work for this project. A revised work plan was developed based on the outcomes of this meeting. In addition, a technology framework was developed to define precision agriculture technology groups specific to nutrient management and to structure the type of information that would be gathered for each technology during the research phase of the project in a data collection template. Data collection categories included the following:

- Costs (CAPEX; OPEX; ROI)
- Technology (Risks and uncertainties; Readiness and years in market)
- Environmental benefits (GHGs; Air; Water; Land; Nutrient considerations, yield, and plant health; Other)
- Commercial success (Market size and dynamics; Market barriers; Competitiveness and alternatives)

The framework and data template, developed in Excel, were used to gather and report on the subsequent research.

Phase 2

Scoping research was conducted in two stages. An initial desk top literature review was carried out identifying publicly available sources of information on relevant technologies. Types of resources identified included company websites and literature, white papers, journal articles and research papers, etc. In terms of companies, the focus was on BC-based companies as available, followed by Canadian and international companies with commercially ready products, applicable to BC. Data, as available, was compiled into the Excel data collection template, organized by technology group.

The second stage of Phase 2 involved industry consultations, as a key source of information to supplement the desk top research (i.e., address gaps, confirm findings, and add new insights particularly with respect to barriers). Interview questions were developed to guide the interviews and are found in Appendix B. Interviews were conducted in two rounds. The first round of interviews was conducted with key informants from BC, Ontario, and other jurisdictions that had general or overarching expertise in precision agriculture and nutrient management.

The second round of interviews was conducted with key precision agriculture companies in Canada and the United States. Fourteen interviews were conducted in total.

Phase 3

A review of the BC farm sector was undertaken to understand factors (e.g., size, crop type, location, farmer age, etc.) that would influence whether precision agriculture technologies for nutrient management would be relevant or appropriate. Once all data was compiled, each technology group was assessed on its potential for application in BC.

Phase 4

A final report was developed (this report), providing an overview of the key findings from the scoping, industry consultation, and analysis. Particular attention was given to precision agriculture technologies for nutrient management that can currently be deployed commercially in BC.

Appendix B: Interview Questions

BC Ministry of Agriculture Scoping Survey

Key Informant Interview Questionnaire

1) Precision agriculture: nutrient management companies, and technologies

Guiding Questions:

1. What types of precision agriculture technologies used for nutrient management are commercialized or commercially-ready? (If not commercially-ready, what is the approximate timeframe to consider?).
2. Within the technology groupings identified above, which companies are currently technology leaders? Are there multiple companies with similar products or are they fairly unique in their offerings?
3. What is your impression on the size of the market opportunities for each of the technology groupings? Will they be competing against other types of technology that fulfill a similar function?

2) Technology Costs

1. What are the typical / average capital and operating costs for the commercialized, or commercially-ready technologies discussed? Do you know where we could get this information?

3) Benefits/impacts Associated with Technologies

1. What are the environmental benefits / measured performance of the technologies we have discussed above (air, GHG emissions, water, land)?
2. What are the economic benefits of these technologies? (only benefits discussed here; costs are discussed in the section above)
3. What are the benefits to product yield and plant health?
4. Any other benefits not covered?

4) Barriers to Precision Agriculture Technology Development / Deployment

1. What are the barriers to implementing the mentioned technologies? Barriers include financial (e.g., capital and operating costs, return on investment), technology (e.g., infrastructure barriers), and policy or acceptance barriers (complexity for end user, regulatory hurdles, risks such as privacy, data security, etc.)
2. For the technologies discussed, are there any additional limitations / barriers for the implementation of the technology in British Columbia?

5) General Sector-related Information

1. In your opinion, from the technology categories discussed above, which could successfully be implemented for nutrient management applications in British Columbia? What technologies would you consider less likely to be successful?

2. What are the global trends in nutrient management related to precision agriculture technologies?

3. What are the current challenges facing nutrient management technology companies in agriculture?

4. What types of funding programs (provincial and federal) are available for precision agriculture technology implementation?

5. What are some important / significant regional, provincial (BC) and/or federal projects taking place that are investigating precision agriculture technologies (i.e., scaling, implementation)?

6. Which types of farms are more likely to adopt precision agriculture technologies (crops, livestock, etc.)?

6) Gaps in the Nutrient Management Sector

1. What are the current gaps in precision agriculture technologies being developed? (e.g., implementation incentives, technology development, 3rd party investment)

2. Which gaps should be prioritized in developing the nutrient management sector?

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Appendix D: Selection of Precision Agriculture Technology Companies

Company Name	Technology Type	Location		Website
AgGateway ADAPT	Application Programming Interface and Data Analytics	USA		https://adaptframework.org/
Acuity Agriculture	Sensors	USA	San Francisco, CA	http://www.acuityagriculture.com/
Ag Data Transparent	Application Programming Interface and Data Analytics	USA		https://www.agdatatransparent.com/
Ag Leader Technology	Guidance and Autosteer Technologies, Application Programming Interface, Variable Rate Technology, Data Analytics, and Sensors	USA	Ames, IA	http://www.agleader.com/
AGCO Corporation	Guidance and Autosteer Technologies, Application Programming Interface, Variable Rate Technology, Data Analytics, and Sensors	USA		https://www.agcocorp.com/
AgDNA	Application Programming Interface and Data Analytics	USA (with Canada, Australia, and NZ reps)		https://agdna.com/
AG-NAV Inc.	Geo-location/Geo-imagery Processing	Canada	Barrie, ON	http://agnav.com/
Agrilyst	Application Programming Interface and Data Analytics	USA	Brooklyn, NY	http://www.agrilyst.com/
Agri-Trend (now owned by Trimble)	Application Programming Interface and Data Analytics	USA		https://agriculture.trimble.com/software/agritrend/
AgSights	Application Programming Interface and Data Analytics	Canada	ON	http://agsights.com/
AquaSpy Inc.	Sensors	USA	San Diego, CA	http://www.aquaspy.com/
Arable	Sensors	USA		http://www.arable.com/
Aurora Biomed Inc	Data Analytics	Canada	Vancouver, BC	www.aurorabiomed.com
BC Robotics	Sensors	Canada	Nanaimo, BC	www.bc-robotics.com
Ceres Imaging	Geo-location/Geo-imagery Processing	USA	Oakland, CA	http://www.ceresimaging.net/
CiBo Technologies	Application Programming Interface and Data Analytics	USA		https://www.cibotechnologies.com/
Clearpath Robotics Inc.	Guidance and Autosteer Technologies	Canada	Kitchener, ON	http://www.clearpathrobotics.com/

Company Name	Technology Type	Location		Website
Climate Corp (Climate Fieldview) (US, with international offices, including Canada)	Application Programming Interface, Data Analytics, Sensors, and Variable Rate Technology	USA		https://climate.com/
ConeTec	Geo-location/Geo-imagery Processing	Canada	Burnaby, BC	www.conetec.com
Conservis Corporation	Data Analytics	USA		https://conservis.ag/
Crop Tracker	Application Programming Interface and Data Analytics	Canada	Ontario	www.croptracker.com
CropMetrics LLC	Variable Rate Technology	USA	North Bend, NE	http://cropmetrics.com/
CropX	Sensors	USA		https://www.cropx.com/
Decisive Farming Corp.	Variable Rate Technology, GPS/GIS, Geo-location/Geo-imagery Processing, Application Programming Interface, and Data Analytics	Canada	Irricana, AB	http://www.decisivefarming.com/
Deveron UAS	Geo-location/Geo-imagery Processing	Canada	Toronto, ON	http://www.deveronuas.com/
DICKEY-john	Variable Rate Technology	USA	Auburn, IL	http://www.dickey-john.com/
Dragonfly	Application Programming Interface and Data Analytics	Canada	Kingston, ON	https://www.dragonflyag.com/
DreamFactory	Application Programming Interface and Data Analytics	USA		https://www.dreamfactory.com/
E.S.I Environmental Sensors Inc.	Sensors	Canada	Victoria, BC	www.esica.com
Echelon Ag	GPS/GIS, Geo-location/Geo-imagery Processing, Variable Rate Technology, and Data Analytics	Canada	SK	https://www.echelonag.ca/
Ecoation	Sensors	Canada	Vancouver, BC	www.ecoation.com
Farmers Edge	Geo-location/Geo-imagery Processing, Application Programming Interface, Variable Rate Technology, Data Analytics, and Sensors	Canada	MB	https://www.farmersedge.ca/
FarmLogs	Application Programming Interface and Data Analytics	USA		https://farmlogs.com/
Farmobile	Application Programming Interface and Data Analytics	USA		https://www.farmobile.com/
FieldIn	Data Analytics	USA	Napa, CA	http://www.fieldintech.com/
Fieldsmart	Geo-location/Geo-imagery Processing	Canada	Rosetown, SK	http://www.fieldsmart.ca/
FTS	Sensors	Canada	BC	www.ftsinc.com

Company Name	Technology Type	Location		Website
Gamaya	Geo-location/Geo-imagery Processing	Switzerland		https://gamaya.com/
GeoVisual Analytics	Geo-location/Geo-imagery Processing	USA	Boulder, CO	http://www.geovisual-analytics.com/
Granular	Application Programming Interface and Data Analytics	USA		https://granular.ag/
GroPoint	Sensors	Canada	North Saanich, BC	https://gropoint.com/
Harrier Aerial Surveys	GIS/GPS	Canada	Nelson, BC	www.harriersurveys.ca
Hoskin Scientific Limited	Geo-location/Geo-imagery Processing	Canada	Burnaby, BC	www.hoskin.ca
iDUS Controls Ltd	Sensors	Canada	Nanaimo, BC	www.iduscontrols.com
Indro Robotics and Remote Sensing	Sensors	Canada	Saltspring Island, BC	www.indrorobotics.com
Iteris	Application Programming Interface and Data Analytics	USA		https://www.iteris.com/
John Deere	Guidance and Autosteer Technologies, Application Programming Interface, Variable Rate Technology, Sensors, and Data Analytics	USA & International		https://www.deere.com/en/index.html
LandView Drones	Geo-location/Geo-imagery Processing	Canada	Edmonton, AB	http://www.landviewdrones.com/
Leading Edge Technologies	Geo-location/Geo-imagery Processing	USA	Winnebago, MN	http://www.dronesforag.com/
Mavrx Imaging	Geo-location/Geo-imagery Processing	USA	San Francisco, CA	https://www.mavrx.co/
MDA	Sensors	Canada	Vancouver, BC	www.mdacorporation.com
Micasense Inc.	Sensors	USA	Seattle, WA	http://www.micasense.com/
Northern ANI Solutions Inc.	Sensors	Canada	Vancouver, BC	www.northernani.com
Osprey Arial Intelligence	Geo-location/Geo-imagery Processing	Canada	Okanagan, BC	http://www.ospreyaerial.ca/
PrecisionHawk	Application Programming Interface and Data Analytics	USA	Raleigh, NC	https://www.precisionhawk.com/
Prospera Technologies	Application Programming Interface and Data Analytics	Israel		https://www.prospera.ag/
Raven Industries	GIS/GPS	USA		https://ravenind.com/
Redfox Unmanned Aerial Solutions	Geo-location/Geo-imagery Processing	Canada	Vancouver, BC	www.redfoxuas.ca
Resson Inc.	Application Programming Interface and Data Analytics	Canada	Fredericton, NB	http://resson.com/

Company Name	Technology Type	Location		Website
Rowbot	Sensors and Agbot	USA		https://www.rowbot.com/
Semios	Sensors	USA (with office in BC)	Vancouver, BC	www.semios.com
Skaha Remote Sensing	Sensors	Canada	Surrey, BC	www.skahasensing.ca
Skycision	Geo-location/Geo-imagery Processing	USA	Pittsburgh, PA	https://www.skycision.com/
Skymatics	Geo-location/Geo-imagery Processing	Canada	Calgary, AB	http://www.skymatics.com/
Smart Fertilizer Management	Application Programming Interface and Data Analytics	USA & UK		https://www.smart-fertilizer.com/
Smart Yields	Sensors	USA	Honolulu, HI	http://www.smartyields.com/
SoilOptix	GPS/GIS and Geo-location/Geo-imagery Processing	Canada	Travis Stock, ON	https://soiloptix.com/
Spitfire	Geo-location/Geo-imagery Processing	Canada	Vancouver, BC	www.spitfiredronesurvey.com
SWIM	Sensors	USA		https://swiimsystem.com/about/
Stream Technologies Inc.	Sensors	Canada	Edmonton, AB	http://www.streamtechinc.com/
Teralytic	Sensors	USA		https://teralytic.com/
TerrAvion	Geo-location/Geo-imagery Processing	USA	San Leandro, CA	http://www.terravion.com/
The Sky Guys	Geo-location/Geo-imagery Processing	Canada	Ontario	https://theskyguys.ca/
TopCon	Guidance and Autosteer Technologies	USA		https://www.topconpositioning.com/agriculture
Trace Genomics Inc.	Application Programming Interface and Data Analytics	USA	San Francisco, CA	https://www.tracegenomics.com
Trimble	Guidance and Autosteer Technologies, Variable Rate Technology, Data Analytics, and Application Programming Interface	USA		https://www.trimble.com/
UAViation Aerial Solutions	Geo-location/Geo-imagery Processing	Canada	Coquitlam, BC	https://www.uaviation.ca/
Ukko	Geo-location/Geo-imagery Processing	Canada	Ontario	https://ukkocanada.ca/
Understory Inc.	Sensors	USA	Somerville, MA	http://understoryweather.com/
UrtheCast	Geo-location/Geo-imagery Processing	Canada	Vancouver, BC	www.urthecast.com
Vantage Canada West	See Trimble (Vantage is a global vision of Trimble Agriculture)	Canada	AB	http://vantage-canada.com/
Vision Robotics Corp.	Sensors	USA	San Diego, CA	http://www.visionrobotics.com
Yara (N Sensor) (UK)	Sensors	UK		https://www.yara.co.uk/crop-nutrition/tools-and-services/n-sensor/