Looking Ahead

Trends and Forces Impacting the Future of the Seed Industry

Agriculture and Agri-food Canada

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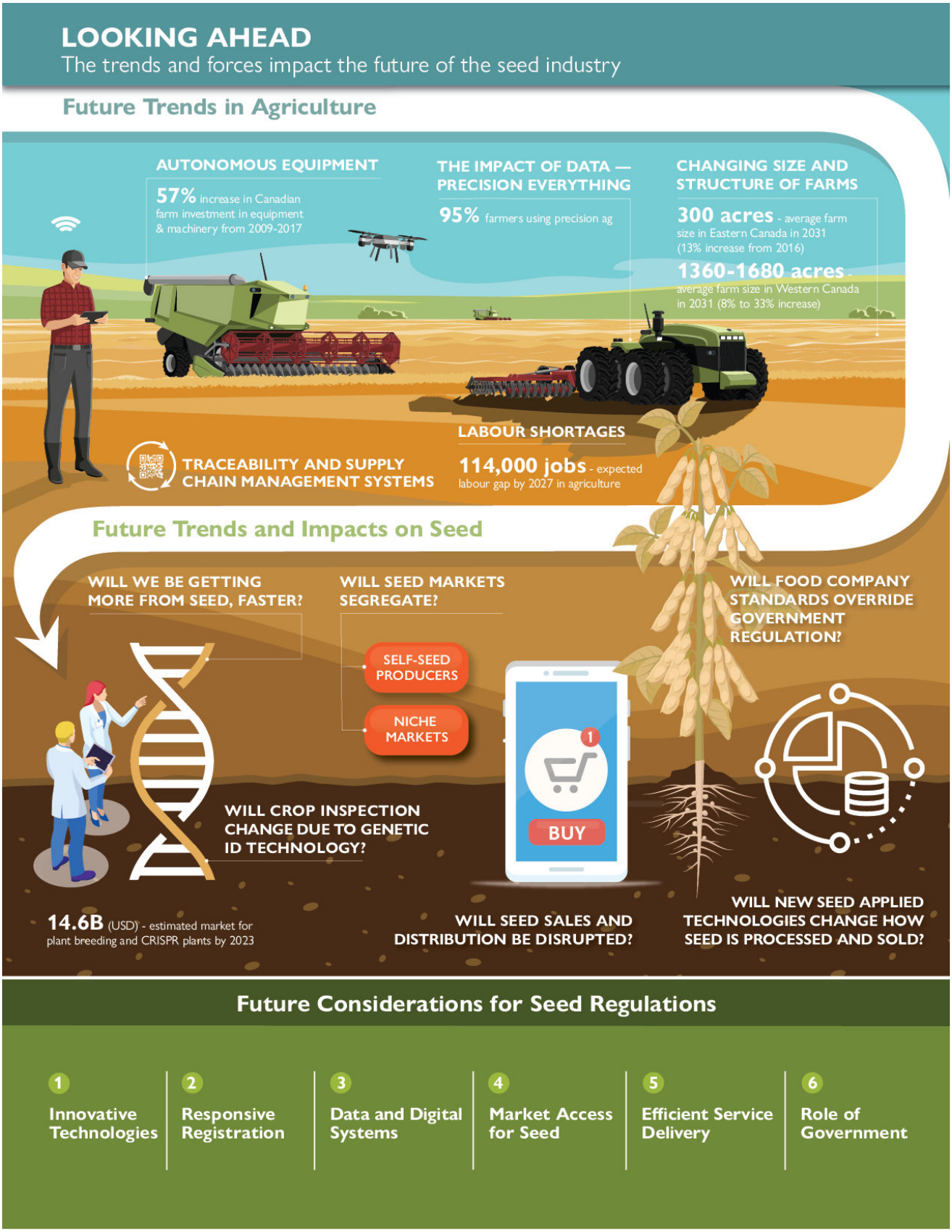


Overview

What will the seed industry look like in 2040? How will seed regulations need to evolve and change? With insight from industry leaders, we've identified the trends, innovations and technology that will impact the sector and shape seed regulations over the next 20 years.

Stakeholders have identified the tremendous opportunity to deliver more solutions — both end use and agronomic — within the seed. Much of this is made possible by faster and more efficient breeding technology, allowing for more diverse trait development to serve the needs of both traditional commodity markets and specialty markets.

The food industry will play a formidable role in the future of seed as efforts to serve emerging and evolving consumer demands drive food industry strategies. Consumer demand for assurances about how their food is produced will drive implementation of traceability and blockchain technologies. We can expect food manufacturers to develop and deliver branded food products — from seed to plate. Canadian farms will also reflect this shift as larger farms expand in size to meet the needs of growing commodity markets while small and medium-sized farms migrate toward serving niche markets.

The expected increase in labour shortages in the agriculture sector will result in increasing adoption of automation and robotics to mitigate this gap.

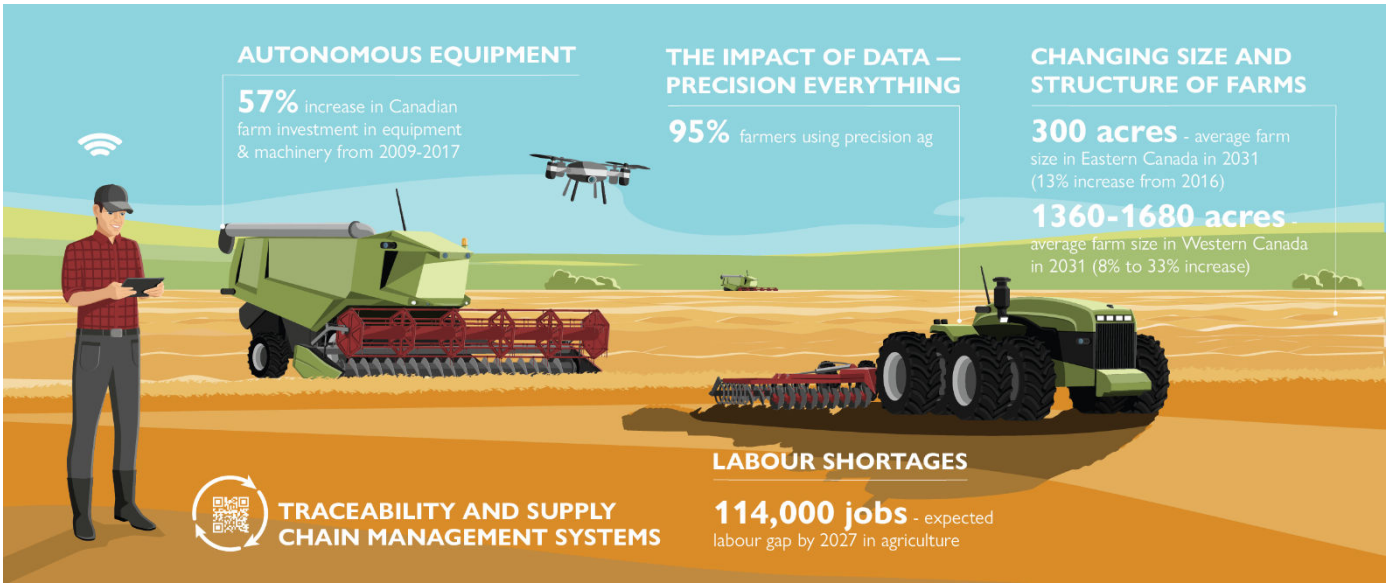
The need for diverse seed traits to meet demand from both food companies and evolving farm operations will also create opportunity for Canada's plant breeders. More cost-effective seed trait development technology and the power of data will allow for a wide range of seed companies to thrive.

"Seed trait development technology and the power of data will allow for a wide range of seed companies to thrive."

Precision agriculture and farm management data will also reshape how farmers interact with a quickly evolving seed sales and distribution system that's ripe for disruption from expanding eCommerce.

To be successful, Canada's seed industry must evolve quickly to keep pace in a highly competitive global seed marketplace. At the same time, Canada is well positioned to take advantage of niche markets and emerging traceability requirements.

Future Trends in Agriculture

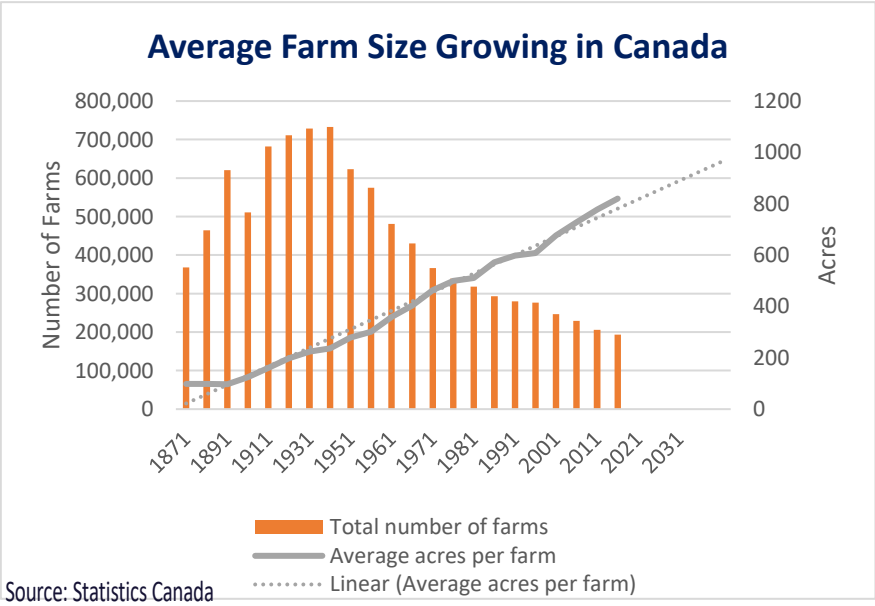


Changing Size and Structure of Farms

Many Canadian farms will continue to grow and increase in size while others will settle into a medium or small category. Bigger farms will pursue efficiency and margins on larger scale crop production (e.g., corn, soybean, wheat, pulses and canola) while medium and small farms will look to capitalize on value-added or IP opportunities.

"Bigger farms will pursue efficiency and margins on larger scale crop production."

The graph below shows a climbing average farm size from 98 acres in 1871 to 820 acres in 2016. Assuming the current growing trend, the Canadian average farm will reach 900 acres after 2031.



Source: Statistics Canada

The changing structure of farming will have implications for the seed industry. As farms get larger and adopt more corporate-based structures (while still being family owned), they will interact more directly with breeders, technology providers and input suppliers. More conventional commodity-focused farms will become fewer, larger and technology-driven to mine data for efficiency and environmental management.

At the same time, this will create opportunities for smaller farms to profitably cater to niche and specialty markets. Certified organic production is just one example of future market opportunities. According to the Canadian Organic Trade Alliance, there were 5,791 Certified organic crop producers in 2018 growing 2.0 million acres of forages and 1.1 million acres of field crops.[1] The market for organic food and beverage products is estimated to be $5.1 billion, growing at an 8.7% compound annual growth rate.[2] The vast majority of these products and ingredients are currently imported which presents a somewhat untapped market for Canadian producers. Niche markets such as these show promise to create new opportunities for seed and grain producers.

Autonomous Equipment

Adoption of automation equipment on the farm and along the supply chain is another key trend. For example, small, autonomous vehicles will be employed by farmers to do many tasks, including planting, weed control and tillage. Autonomous fleets of small power units and implements will operate in a swarm approach to cover the field and help reduce soil compaction along the way. From 2009 to 2017, the average Canadian farm investment in machinery and equipment rose by 57% from $41,000 to $65,000.[3] In 2019, $176 million were invested globally on farm robotics, mechanization and equipment.[4]

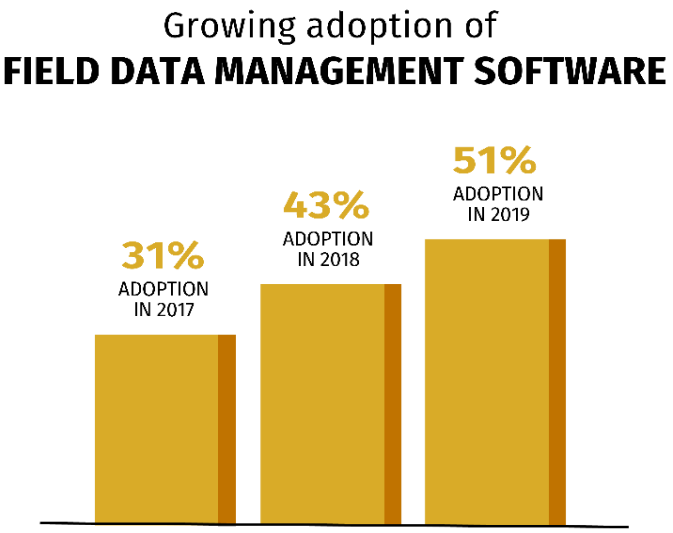
Automated technology will prove effective on both large and small-scale farms. History has illustrated how early adopters are often smaller farms, such as the case with Canadian dairy operators who began utilizing automated robotic milking technology more than a decade ago.

Automation will also play a role in how farmers manage their crops. Increasing consumer pressure to reduce pesticide use on the crop will fuel growth of automated micro-targeted spraying and tillage equipment capable of sensing, identifying and extracting specific weeds. Mechanical weed control will return, but in a whole new way.

[1] Canada Organic Trade Association (2018) Organics in Canada By the Numbers
[2] Canada Organic Trade Association (2019) Quick facts about organic in Canada
[3] Statistics Canada. Table 32-10-0104-01
[4] AgFunder (2019) Agri-FoodTech Investing Report

The Impact of Data — Precision Everything

Precision agriculture will revolutionize how farmers choose and purchase seed. Over the next decade, more farmers will use their own data generated from on-farm replicated trials and testing to determine variety selection for their farm. They will no longer rely solely on seed company research and public trials for their selection recommendations. Farmers will be more integrated with researchers to do large scale replicated trials on-farm. Crop input decisions will also utilize additional data, including soil moisture content, short and medium-term weather, and moisture models to determine planting intentions.



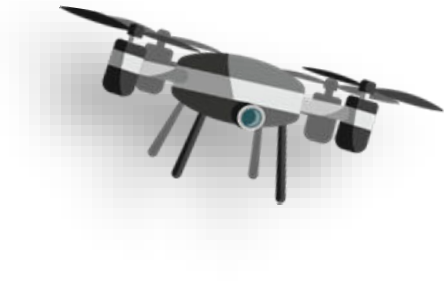
Source: Stratus Ag Research Dynamics of Data Ag Canadian, 2019

A recent Canadian survey showed that approximately 85% of respondents are using some type of precision agriculture tool or service on their farm, while over 75% of Canadian farmers intend to use more precision agriculture tools in the future.[5] In 2017, 84% of field crop producers used GPS tools, with 90-95% adoption rates in the Prairies.[6] In 2019, 51% of farmers used field data management software, compared to 43% in 2018 and 34% in 2017.[7] These trends were even higher for young farmers and for large size farms.

Traditional seed guides won't exist as we know them today. Farmers will use their own data, and also consider company data as well as farmer on-line ratings collected from across the country to make seed purchase decisions. Based on this information, farmers will determine the most profitable, highest-yielding varieties that are the best match for their soil type and growing environment with the market for their crop. Then, they will seek out suppliers to fill their needs. Data will also help farmers better understand the impact of climate change and identify effective variety selection and input decisions such as growing drought-tolerant varieties using variable planting rates across the field.

"Traditional seed guides won't exist as we know them today."

Precision agriculture will also evolve. Competing farm data programs and systems will converge and merge to provide better interconnectivity and easier data management. This will make data a truly effective crop and farm management tool. Access to field performance data will also shape product and program offers from seed and input companies as well as crop insurance options for farmers, including more private insurance company policies and coverage options.



We can also expect farmers to employ Artificial Intelligence (AI) and machine learning. These tools will have the capability to produce reports based on farmer production data, and market and weather

[5] Analysis of Precision Agriculture Adoption & Barriers in western Canada Producer Survey of western Canada And Expert Panel Summary, Dan Steele on behalf of AAFC.
[6] Statistics Canada, Environment, Energy and Transportation Statistics Division.
[7] Stratus Ag Research Dynamics of Data Ag Canadian 2019

information, to recommend what farmers should be growing and how to grow it. Internet of Things (IoT) refers to the increasing connection of devices such as smartphones, tablets, farm equipment and vehicles to the internet. Sensing and monitoring devices are applied in precision farming to avail data that help farmers monitor and optimize crops and well as adapt to changing environmental factors.

Sensor technology has allowed specific real-time sensing of many different aspects (e.g. products, the environment). What was previously a central lab analysis has moved to the farm level. Results are now available in real time instead of days or even weeks. Sensors with small-scale control systems with robust functionality would allow indoor farms to better automate their systems and increased yields. The combination of IoT and advanced sensors are likely to drive the availability and communication of farm data in the future.

Traceability and Supply Chain Management Systems

Food production will be influenced by the growing interest from consumers to know where their food is coming from and how it is produced. Traceability and supply chain management systems like blockchain and other digital management systems will be part of the solution to meet this demand for more information. For example, IBM Food Trust™ is a blockchain network that connects participants in the food supply through a shared, permanent record of food system data. It enables transaction partners to securely share information, increasing confidence in food safety, sustainability, and other practices to create a more transparent and trustworthy global food supply chain[8].

HarvestMark, a division of Trimble, is a second example of a traceability and blockchain provider that is meeting the demand from consumers for information about their food. HarvestMark Connect enables fresh food brands to engage shoppers in real-time through any mobile device. Consumers can access grower information, recipes and give feedback through the application. Its blockchain applications help to streamline regulatory and audit requirements, improve supply chain efficiency and speed-up grower settlements in addition to enabling traceability within seconds[9].

New technologies are also changing the way we trace and detect variety information and identity. Nucleic acid amplification (e.g. PCR) can be used to identify varieties using genetic fingerprints such as SNPs (single nucleotide polymorphisms). In addition to the detection of these DNA markers used by breeders, it has been proposed that seed developers can introduce unique, short DNA sequences into genomes that could function as watermarks to uniquely identify proprietary genetic material. The most recent generation of DNA amplification

[8] https://www.ibm.com/blockchain/solutions/food-trust
[9] https://www.harvestmark.com/

equipment includes hand-held, battery-operated portable instruments that generate results in one hour, which permits the use of DNA amplification technologies in the field. In addition to PCR-based (DNA amplification) methods, high-throughput next generation sequencing (NGS) of DNA has made it feasible to rapidly and cost-effectively sequence genomes for plant or seed identification.

Whole genome sequencing methods are becoming the standard in food safety testing and could be routinely implemented in varietal identification. Other methods to identify specific varieties could include metabolite profiling such as chromatography-mass spectrometry and nuclear magnetic resonance (NMR) imaging, or the detection of volatile organic compounds by an electronic nose. Such methods are routinely used in food fraud studies to determine product purity, the place of origin of food products, and other food attributes. There are several new technologies for the evaluation of seed quality also being developed, including spectral analysis and biosensors. Spectral imaging technologies such as near-infrared spectroscopy and hyperspectral imaging are non-destructive methods that involve scanning seeds to develop a chemical and spatial map of the seed. Thermal imaging (i.e. scanning the infrared radiation emitted by the seed) is also being developed as a method for seed quality testing. These spectral scanning methods could potentially provide rapid, non-destructive tests to determine seed viability, to detect pathogens seed damage or impurities, or for seed classification and variety identification.

Labour Shortages

In 2017 the Canadian agriculture sector had a labour gap of 59,000 jobs, which is expected to rise to 114,000 jobs by 2027. This is the highest job vacancy rate of any industry. According to the Canadian Agricultural Human Resource Council, Canada could gain $11 billion in annual GDP by 2030 by closing the agriculture labour gap and accelerating investment in technology. This would bring agricultural GDP to $51 billion, making it bigger than automobile assembly and aeronautics combined. Technology like automation and robotics will be part of the solution to mitigate the labour shortage that inhibits agricultural productivity.

Future Trends and Impacts on Seed

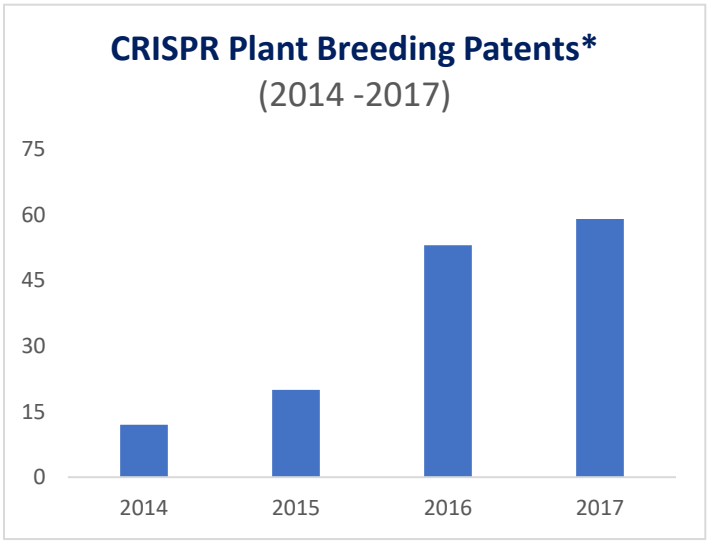
Getting More from Seed, Faster

Over the next two decades Canadian agriculture will have an opportunity to get more from seed. New seed traits will reduce the levels of fertilizer and pesticides required to grow crops as well as the need for insecticides to protect against pests.

Complex stacks of existing technology will continue to emerge – triple herbicide tolerance and multiple modes of action, for example, will help farmers manage an increasing number of herbicide-resistant weeds, which will continue to prove challenging. Seed breeders also expect to see a higher level of seed interaction with soil. Varieties will be developed to work with soil microbes, bacteria and fungi, to create benefits for plants and crops. We'll move beyond just traits, and create interactions that increase nitrogen and phosphorous use efficiency and enhance tolerance to pathogens, just to name a few potentials we see on the horizon.

"These technologies will accelerate trait development, be more affordable for breeders and allow more players — both public and private — to participate in the plant breeding business."

The speed of these innovations will increase with the adoption of innovative gene editing technology such CRISPR-Cas9 and genomics, phenomics and speed breeding. These technologies will accelerate trait discovery and development, be more affordable for breeders and allow more players — both public and private — to participate in the plant breeding business. These technologies will also create efficiency, allowing plant breeders to make specific and directed genetic changes faster, with greater predictability compared to current breeding and biotechnology techniques. The graph below shows the rapid increase in worldwide patent filings that involve CRISPR plant breeding. The majority of patents were filed by applicants in China (78%) and the U.S. (17%), while Canadian applicants filed one plant breeding CRISPR patent during this time period.



*Data adapted from: Martin-Laffon, J., Kuntz, M. & Ricroch, A.E. Worldwide CRISPR patent landscape shows strong geographical biases. Nat Biotechnol 37, 613–620 (2019).

Technology such as gene editing also promote participation in the breeding industry, providing opportunities for small and medium-sized seed companies to concentrate on varietal development to fill market niches. These companies will also develop new commodity-based varieties and hybrids and sell multiplication and distribution rights to larger companies. These accessible and affordable "open source" breeding technologies will encourage more start-ups with niche breeding that will cater to closed-looped or IP systems. Other niche-market breeding opportunities could include "artisanal breeding" for new and emerging farm sectors such as urban farming.

There is also growth opportunity to be seen from hybridization. Hybrid corn and hybrid canola revolutionized those crops and brought about significant growth in yield and acreage globally. Hybridizing other crops is often much more complicated as a result of more complex genetic structures but research is underway. Hybrid wheat and hybrid potato research is already quite advanced. While success currently may seem far away, new technology and genetic research very well may create a path forward for these crops.

Overall, we expect to see more plant breeding activity in many crop types and from many different players given this new scientific era. Private investment in plant breeding is expected to increase. A recent market survey report indicates that the plant breeding and gene edited plants market is expected to grow from an estimated $7.68B (USD) in 2018 to $14.6B (USD) in 2023, mostly driven by investment in genomics and modern breeding techniques[10]. Public breeding programs are also evolving to adapt to changing technology and changing needs.

Current Status on PNTs

The Canadian seed industry needs direction from Canadian regulators on how CRISPR-Cas9 and gene editing will be regulated. Lack of firm regulatory direction creates significant risk for the Canadian seed industry.

To address this risk, the Government of Canada has been working with the seed industry and other stakeholders on providing regulatory clarity for products of biotechnology.

Competitors such as Japan have announced that special labelling is unnecessary for products created through these new breeding techniques because they do not require the introduction of foreign DNA. Japan joins countries such as the U.S., Australia, Argentina and Chile in not applying extra scrutiny to new traits resulting from gene editing.

Seed Applied Technologies

Seed applied technologies such as treatments and coatings also offer tremendous potential to improve crop production and further increase the value of seed. Developments in fungicides and insecticides have enabled greater seed protection and improved yields in the past decade, but looking forward the future is even brighter with the inclusion of nematicides, inoculants and other biologicals that reduce plant stress or promote plant growth.

Current examples of seed treatments in development include Agrynex's ZymGuard™ seed coating, which is a formulation of enzymes (e.g. biocidal and fungicidal proteins) as a seed treatment alternative to pesticides. Biostimulants are substances and/or microorganisms that enhance plant growth. Biostimulants can be substances such as protein hydrolysates that can provide protein building blocks or seaweed extracts that may provide a source of minerals to the developing plant. Some biostimulants promote the growth of beneficial

[10] MarketsandMarkets™ Report: Plant Breeding and CRISPR Plants Market by Type (Conventional and Biotechnological [Hybrid, Molecular Breeding, GM, Genome Editing]), Trait (Herbicide Tolerance, Disease Resistance, and Yield Improvement), Application, and Region - Global Forecast to 2023

microbes that may deter pathogen growth, while other products may be microbes that may live inside the plant itself in a beneficial relationship (e.g. nitrogen-fixing inoculants) or microbes that live on the surface of the developing plant root and provide nutrient to support plant growth. For example, Pivot Bio has identified a nitrogen-fixing microbe that lives on corn roots, which can provide a source of fixed nitrogen to support corn growth and reduce the need for synthetic fertilizers. Available currently as an in-furrow treatment, the company is developing a seed treatment formulation containing the microbe.

Innovative Technologies for Varietal ID

Similarly, we can expect other technological advancements will have a significant impact on the seed trade. Advancements have the potential to enhance, disrupt and significantly change nearly all aspects of the seed trade including registration mechanisms, crop production, fraud prevention and intellectual property protection.

One genotyping technology that could be used for varietal identification is Single Nucleotide Polymorphism (SNP). SNPs can be used to identify a variety at either the seed production level or in a grain sample. This has potential to alter many aspects of the seed value chain. Argentina has started implementing this new method to identify soybean varieties. SNP information must be included to register a new variety at the commercial level and it's also being used at the breeding level to expedite verification and profiling of new varieties as they come up for registration.

If this technology takes off and proves useful in Argentina, we can presume it will significantly adjust the registration process for new varieties and hybrids in many countries. Phenotype-based registration systems will no longer be required and there will be a need for increased lab capacity to manage the molecular testing required for this new assessment criteria. This technology also has the potential to alter seed production and the pedigreed seed process. Technology could enable movement away from a process-based system towards an analysis-based system. Such a transition could eliminate the need for field inspections with movement towards post-harvest testing.

This technological advancement also has the capacity to significantly alter value capture, fraud prevention and intellectual property enforcement. In Argentina, implementation of this technology, will result in increased assurances that what was declared by the farmer is what was actually planted. At the commercial level this will be used to verify what was actually grown in the crop by testing in field or sampling of the harvest grain.[11] As with most technological advancements, resistance and challenge should be anticipated. Currently, some stakeholders are advocating to move away from analysis-based systems and to rely on process-based systems, such as for low level presence of GM traits. The reliability of varietal ID systems will significantly impact the marketplace to rely on either process-based systems or could create markets that prefer or demand analysis-based systems.

[11] https://efarmnewsar.com/2019-04-08/identification-and-control-of-soybean-varieties-via-dna-almost-ready-to-be-implemented-this-year.html

Seed Market Segmentation

> ***"Farmers and the seed industry will experience much greater demand for traceability and food tracking."***

Over the next 20 years, seed markets will continue to diverge into separate market segments. This segmentation will be driven by the need to serve large farms with trait technology and new genetics as well as smaller farms that cater to boutique markets with niche needs such as identity preserved production of specific value-added traits, Certified organic or other special markets. These niche or boutique markets will grow, in part, due to the proliferation of data technologies like blockchain and its ability to link the steps in the supply chain together and validate information required for identity preserved (IP) and closed-loop systems.

Plant breeders and seed companies are likely to "integrate" into the value chain more and more. Successful breeders will develop strong downstream relationships with end users allowing specific varieties to flow through to specific end-use markets. Small and medium farmers will become a vital business opportunity for seed companies as they produce seed for niche and special markets.

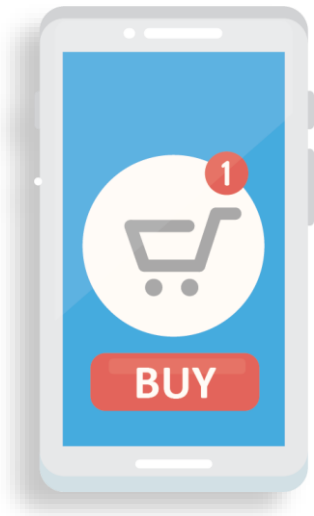
Large farms may become "self-seed producers" licensing genetics directly from a seed distributor or plant breeder. As these operations grow and farm 50,000 or 100,000 acres, they will possess the size and scale to grow their own seed from foundation class. The growth of corn and soybean acres in Western Canada and the potential for breakthroughs in other crops could also create considerable opportunity for farmers and seed growers.

Food Company Standards Override Government Regulation

Food companies will have more opportunities to develop branded products using their own seed genetics developed through working partnership with plant breeders. This will provide control of all aspects of production including taste, quality and marketing. They will also have the ability to meet consumer needs for food traceability and offer consumers an understanding of how their food is produced. This model may closely resemble the IP efforts of British baker Warburtons and their efforts to source specific seed varieties to grow wheat in Canada to produce bread loaves for U.K. customers, but could expand to be more mainstream.

Farmers and the seed industry will also experience much greater demand for traceability and food tracking from "the final mile" as food companies seek to meet demands of consumers who place high value on knowledge of how their food was produced. Food companies will also exercise greater power to enforce these standards throughout the value chain. For example, marker gene technology could be used to determine the seed variety used in manufacturing and verify product claims. Currently, this type of activity is already taking place for cannabis strain identification and tracking. For example, Medicinal Genomics, a cannabis service company, offers a StrainSEEK® Strain Identification and Registration Service which develops a genetic fingerprint for cannabis strain identification and submits an encrypted version of this data to the DASH blockchain. This serves as a timestamped record of the strain genetic fingerprint for intellectual property purposes and also provides a method for seed-to-sale strain verification.

Seed Sales and Distribution — Ripe for Disruption



Many economic sectors have been impacted by disruptive technology and services: banking has adopted self-service; traditional retail is being revolutionized by internet order and the delivery power of Amazon; and many companies have traded mainframe computer and IT departments for cloud-based host servers and subscription-based software. Hotels, taxis and grocery stores are all being disrupted. The list goes on.

Seed sales and distribution are also ripe for disruption. The evolution of North American livestock feed companies is a strong example of the changes set to occur in the crop input business. Today, feed companies no longer operate several small local feed plants, opting instead for fewer centralized larger plants with stringent quality assurance programs and more just-in-time feed delivery.

Canada's crop production industry covers a large landscape and centralizing retail seed distribution will prove challenging with vast distances between farms and distribution points. But eCommerce will be a disruptor as it enables farmers to shop based on price. Many farmers will use their precision ag data to identify the best varieties and maintain formal relationships with seed companies and retailers. Other farmers will ignore the guidance of data and agronomic advice and purchase seed based solely on price through eCommerce. The onset of Farmers Business Network in Canada recently is foreboding.

Seed retail and distribution will continue to experience pressure as farmers ask to pay less for seed and suppliers charge higher prices to provide a return on investment for their R&D, breeding and production costs. Larger seed and crop protection input suppliers who have pursued scale and efficiency through mergers and consolidation feel that they are positioned to react effectively, but time will tell.

There will be opportunities for seed and input retailers who invest in precision agriculture management. These businesses will position themselves to fill custom orders for individual fields and provide field management prescriptions and supply all the recommended inputs including seed.

Future Considerations for Seeds Regulations

Understanding trends that will shape Canada's agriculture and seed industry provides great insight for seed regulators. Over the next 20 years, technology will enable plant breeders to develop better plant genetics, faster. These genetics will help shape Canadian farms — their size, what products they grow and how they do business with their suppliers.

Seed will also power the development of new, innovative, healthy food products to serve emerging niche markets and also meet the growing needs of commodity markets. Food companies will play a greater role in catering to the unique needs of consumers, including providing knowledge of crop inputs and how food ingredients are produced on the farm.

"Many farmers will use their precision ag data to identify the best varieties and maintain formal relationships with seed companies and retailers."

The proliferation of precision farming and data will significantly reshape agriculture and the structure of agribusinesses as disruption occurs throughout the value chain — from seed to plate.

The implications for Canada's seed regulations are numerous and significant. From the need to adopt new seed breeding technology to embracing agile and technology enabled seed certification and inspection protocols, Canadian seed regulations must change and adapt to enable future seed industry success.

Here are some considerations and questions to think about for modernizing Canada's Seeds Regulations…

1 Innovative Technologies

Will traditional seed crop inspection one day be replaced with inspection using drones or post-harvest molecular testing of seed?

2 Responsive Registration

Is the variety registration system able to be nimble and responsive to future market needs?

3 Data and Digital Systems

Will the increase of farm data management and food traceability systems have any implications on how Seeds Regulations should be structured?

4 Market Access for Seed

How can we ensure that Canadian produced seed has a "passport" to access global markets?

5 Efficient Service Delivery

Are there any other opportunities for alternative service delivery in seed?
Is there anything in the current system that no longer needs to be done?

6 Role of Government

What aspects of the system should stay with government?
What aspects should move to industry delivery (with government oversight)?