KPU Institute for Sustainable Food Systems

Toward Ecologically, Economically and Socially Beneficial Agricultural Technology Adoption in BC

A discussion note for policy and decision makers

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The Institute for Sustainable Food Systems

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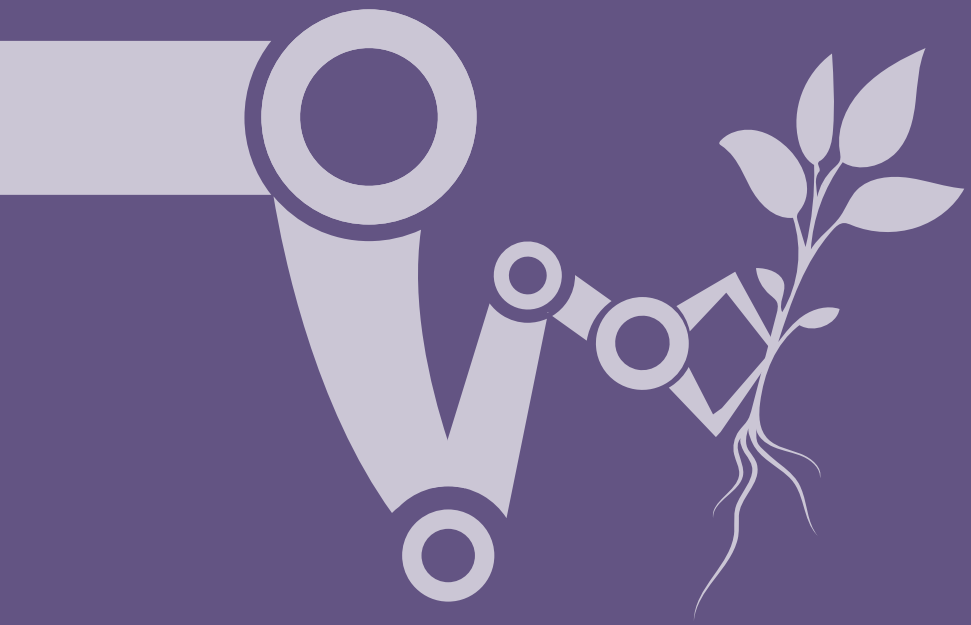

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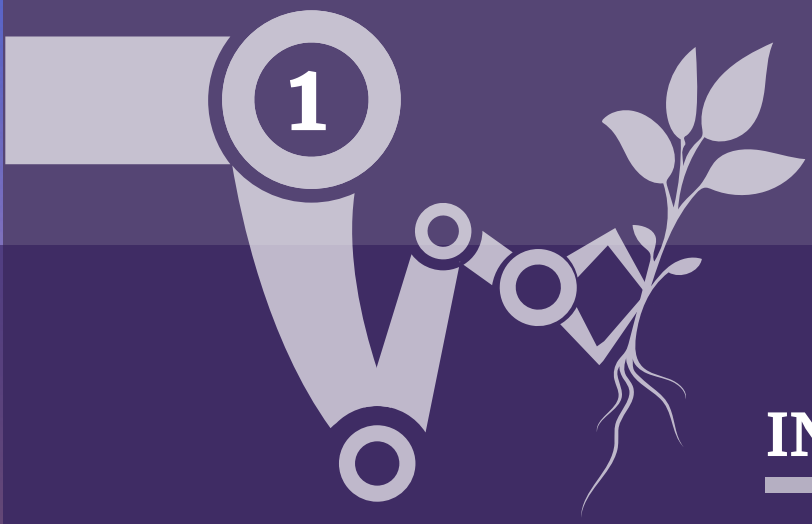


INTRODUCTION

1.1 Purpose of this Discussion Note

Policy in BC and Canada is increasingly advancing agritech as a solution to many of the challenges facing contemporary agriculture: Emerging capital intensive, proprietary agricultural technologies (agritech) are being proposed to address a wide range of challenges including labour shortages, food security, resource stress, climate change, etc.

Many advocate that these emerging agritech innovations, such as precision agriculture, genome editing, automation, big data analytics, vertical farming etc., comprise a fourth agricultural revolution with the potential to redefine food production in Canada [1], [2] to be more profitable and ecologically sustainable. At the same time, there are concerns that "fourth wave" technologies are positioned to deepen inequities in the food system, [3], [4], [5] and that technological intervention alone is an insufficient strategy to achieve the proposed ecological [6] and economic goals [7].

This note aims to inform current and future policy discussions to advance technologies that are ecologically, socially, and economically beneficial and uphold the public interest. To do so, this note provides a high-level summary of agritech benefits and concerns based on historical precedents, presents a framework to highlight the ecological, social and economic impacts of agritech interventions, and discusses key principles to guide related policy development.

A Note About What This Discussion Is Not

This note is not a categorical opposition to technological applications in agriculture. Technology has, and will continue, to contribute to addressing challenges in agriculture. However, this note does recognize that, over the course of the 20th and 21st centuries, technological development and adoption in agriculture has generated several challenging social, economic, and ecological conditions in the food system, often under the myopic goal of increasing efficiency and yields. The authors believe that emerging technological innovations should be informed by this historical context. Given the high levels of public investment currently dedicated to advancing agritech innovation, the authors aim to emphasize the importance of considering a broader range of potential impacts to understand the merit of agritech investment. We hope to encourage policymakers to learn from the past, and exercise care and thought about the scale and scope of agritech interventions, their policy environments, beneficiaries, and impacts, both intended and unforeseen.

1.2 Agriculture & Technology

Agriculture has been subject to extensive technological innovation over the course of the past 70 years, with both positive and negative impacts. Industrial agritech such as mechanization and synthetic chemical inputs, have facilitated unprecedented productivity in the Canadian agricultural sector. For example, between 1960-2023, the average yield of canola (bushels per acre) has increased by 140%, and the average yield of spring wheat has increased by over 100%. [8] Since 2000, overall tonnes of Canadian chicken production have increased by 40%. [9] Additionally, technologies have yielded economic efficiencies by increasing output levels with a smaller, lower-paid workforce.[10] Because of industrial agritechnologies, the sector experienced significant structural changes, including a massive decline in labour requirements, an increase in the use of synthetic inputs in the production process (e.g. fertilizers and pesticides), and an increase in the influence of agribusiness research and development on farming practices. [11]

It is important to note that the ecological, social, and economic costs of these changes and efficiencies have been profound. Some examples are listed below.

ECOLOGICAL

Canadian fertilizer consumption has more than doubled since 1990 [12] and approximately tripled since the 1980s, with significant ecological impacts:

Excess nutrients, particularly from synthetic fertilizers, are the leading cause of freshwater contamination in Canada.[13] Additionally, fertilizers are responsible for a notable and increasing portion of agriculture greenhouse gas emissions. [14] When emissions from the production and application of nitrogen fertilizers are included, greenhouse gas emissions from agriculture have approximately doubled since 1990. [15]

ECONOMIC

Increased production costs and farmer debt loads:

Canadian farms are highly indebted as the profit margins of farm businesses have decreased. Despite increases in productivity, total farm debt in Canada has more than doubled since 2000 [16], and measures approximately 140 billion.

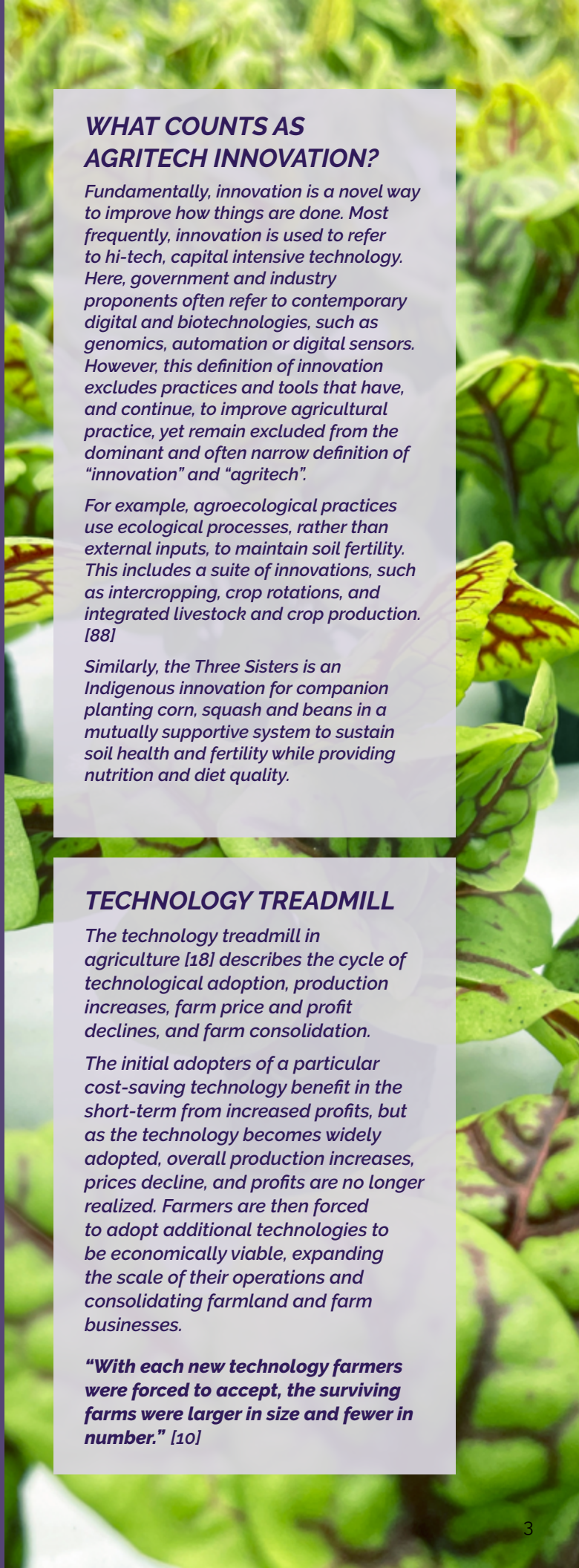
SOCIAL

The erosion of family farming and rural economies as farmland is consolidated into fewer, larger operations to keep up economically:

Between 1951-2016, the number of farms in Canada has decreased from 480,000 to less than 200,000, while average farm size has increased from approximately 360 acres to 820 acres. [17]

Canada and BC are investing significantly in agritech development and commercialization. For example, in 2019 the Canadian Agri-Food Automation and Intelligence Network [19] received $49.5 million of federal funding. In 2022, AAFC invested over $15.2 million under the Agricultural Clean Technology program to support green energy and energy efficiency, bioeconomy and precision agriculture. [20] That same year, Genome BC and the Investment Agriculture Foundation of BC each invested $1M to jointly fund the Genomic Innovation for Regenerative Agriculture, Food and Fisheries Program to invest in "genomic solutions that enhance the agriculture, food and fisheries sectors, increasing resiliency and sustainability in BC". [21] Also in 2022, the B.C. Centre for Agritech Innovation, at Simon Fraser University, was launched with $16.5 million in federal and provincial investments, to "bring together academia, government and the industry to create more productive, diverse and resilient food-supply chains". [22] In 2023, the BC Ministry of Agriculture announced $3 million for the On-Farm Technology Adoption Program to increase farmer access to digital and robotics technologies. [23]

While many government and industry actors have promoted the benefits and opportunities associated with hi-tech agricultural innovations, there are concerns that the current agritech agenda is at risk of repeating policy decisions that, in the past, have yielded problematic ecological, social and economic outcomes.



WHAT COUNTS AS AGRITECH INNOVATION?

Fundamentally, innovation is a novel way to improve how things are done. Most frequently, innovation is used to refer to hi-tech, capital intensive technology. Here, government and industry proponents often refer to contemporary digital and biotechnologies, such as genomics, automation or digital sensors. However, this definition of innovation excludes practices and tools that have, and continue, to improve agricultural practice, yet remain excluded from the dominant and often narrow definition of "innovation" and "agritech".

For example, agroecological practices use ecological processes, rather than external inputs, to maintain soil fertility. This includes a suite of innovations, such as intercropping, crop rotations, and integrated livestock and crop production. [88]

Similarly, the Three Sisters is an Indigenous innovation for companion planting corn, squash and beans in a mutually supportive system to sustain soil health and fertility while providing nutrition and diet quality.

TECHNOLOGY TREADMILL

The technology treadmill in agriculture [18] describes the cycle of technological adoption, production increases, farm price and profit declines, and farm consolidation.

The initial adopters of a particular cost-saving technology benefit in the short-term from increased profits, but as the technology becomes widely adopted, overall production increases, prices decline, and profits are no longer realized. Farmers are then forced to adopt additional technologies to be economically viable, expanding the scale of their operations and consolidating farmland and farm businesses.

"With each new technology farmers were forced to accept, the surviving farms were larger in size and fewer in number." *[10]*

1.3 Summarizing Agritech Benefits and Concerns

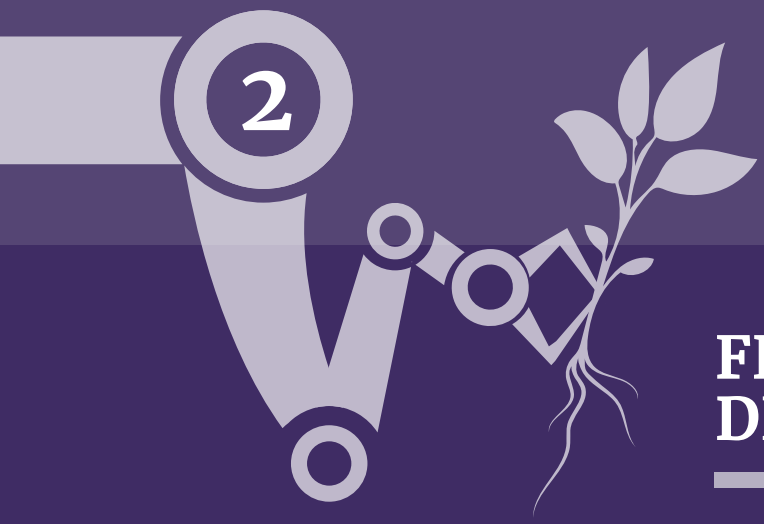
The following table summarizes the generalized benefits and concerns expressed by agritech proponents and critics. Overall, agritech proponents highlight the potential efficiency gains from agritech adoption. Proponents advocate that increased efficiencies can yield both economic gains and environmental advantages, while producing more food to "feed the world" thereby addressing food insecurity.

On the other hand, critics argue that the economic gains from agritech are likely to disproportionately benefit a small number of wealthy agribusiness actors, reinforcing existing inequalities in the food system. They add that these economic efficiencies have unaccounted social and ecological costs and that that the stated environmental advantages of increased efficiency have not materialized and are therefore unsubstantiated. Furthermore, the assumption that increasing food production will address food insecurity obscures the root causes of food insecurity, namely poverty and inequality, and not scarcity.

AGRITECH IMPLEMENTATION

Summary of benefits and concerns with agritech implementation as expressed by proponents and critics

	BENEFITS	CONCERNS
ECOLOGICAL 	**A. Environmental protection or climate change adaptation by** • Increasing the efficiency of resource use and inputs including water, land, fertilizers, pesticides, energy etc.	**A. Ecological degradation by** • Focusing on efficiency at the margin and ignoring total aggregate resource use and aggregate waste generation. See the Jevons Paradox. • Facilitating structural shifts in agriculture with unintended or ignored ecological impacts
ECONOMIC 	**B. Increasing farm profitability by** • Reducing labour costs, or addressing labour shortages, through mechanization and automation • Increasing yields • Improving crop quality, standardization, etc.	**B. Compromising farmer livelihoods by** • Increasing farmer debt through high investment/financing costs and increasing operating costs from additional inputs • Reducing skill, pay, abundance of agricultural work
SOCIAL 	**C. Improving food security and health by** • Increasing food production to "feed the world" **D. Improving workplace safety by** • Automating dangerous tasks	**C. Reinforcing food insecurity by** • Obscuring the root causes of food insecurity, namely poverty and inequality **D. Yielding adverse human health impacts by** • Facilitating unintended or ignored impacts to the health of agricultural workers and the general population **E. Reinforcing inequalities and consolidating power by** • Limiting agritech access to wealthy actors through high investment costs • Promoting consolidation and privatization • Promoting dependence on relatively few agritech suppliers **F. Displacing farmers, land-based knowledge, and local decision-making capacity by** • Replacing agricultural jobs with automation • Supplanting place-based knowledge and practice with uniform technological approaches • Eroding local decision-making capacity over agricultural systems through consolidation and privatization



2 FRAMEWORK FOR DECISION-MAKERS

The following framework presents a series of questions for policymakers when considering policy support for agritech. The goal of this framework is to inform policymaking that is ecologically, socially, and economically beneficial for communities and ecosystems. The framework encourages policymakers to consider a broad range of impacts, particularly in areas overlooked by previous technological adoption. While it does not provide a comprehensive list of all considerations that should inform agritech policy, it highlights important and often overlooked questions to promote discussion and nuanced policy development. Additions and revisions are encouraged to reflect local context and goals.

IMPACTS	QUESTIONS	KEY CONSIDERATIONS
ECOLOGICAL 	1. How might the technology impact ecosystem integrity and biodiversity?	• Habitat and biodiversity • Resource consumption • Unforeseen or ignored structural shifts in food production
ECONOMIC 	2. How might the technology impact farmer livelihoods and rural economies?	• Farm profitability, net income, and debt
SOCIAL 	3. How might the technology impact consolidation in the food system?	• Privatization • Market consolidation
	4. What might the technology displace?	• Agricultural land • Local knowledge • Alternative approaches
	5. How might the technology impact community health?	• Farm workers and rural communities • General population

Ecological Impacts

Question 1. How might the technology impact ecosystem integrity and biodiversity?

Agriculture is a major driver of ecosystem degradation and biodiversity loss in Canada. [27], [28] Agritech has facilitated several large-scale, structural changes in the way food is produced, often with unintended impacts. For example, the movement of excess nutrients, particularly from synthetic fertilizers, into adjacent water bodies is the leading cause of freshwater contamination in Canada. [13] There is a need to increase the ecological integrity of agricultural landscapes and the surrounding ecosystems by regenerating soil health and biodiversity, and by reducing agrochemical pollution. While technological applications can assist with these goals, there is also a need to understand and prevent additional undesirable outcomes.

For example, several emergent innovations are being proposed to reduce agrochemical use, such as pesticides. Ongoing research is examining the use of gene editing to reduce weed pressures by re-sensitizing weeds to herbicides, [6] or using gene drives for auto-extinction of undesirable weeds. [29] Proponents advocate that these technologies can reduce or eliminate the need for herbicide applications. However, critics warn of unintended effects of gene editing applications including changes to non-target organisms, and threats to biodiversity if gene drive technologies were released into the wild. Critics also argue that continuing to focus on making crops resistant to herbicides will ultimately result in more herbicide dependence and use. [30] The historical record of agritech adoption provides examples of unforeseen ecological impacts, some of which are reviewed in greater detail in this document. While a more comprehensive review is outside the scope, this component of the framework seeks to learn from this context and promote a thoughtful and nuanced policy environment for future agritech pursuits.

Economic Impacts

Question 2. How might the technology impact farmer livelihoods and rural economies?

For many farms in Canada, farm income is increasingly insufficient to cover costs. Farm debt in Canada has been increasing dramatically, particularly since the late 1990s, reaching almost $140 billion in 2022. Since 2000, Canadian farm debt has more than doubled. [16] It should be noted that Canadian farmers as a whole have continued to increase production and sell products. Gross revenues received by farmers from the market have increased over this time. However, researchers note that farm expenses have also increased. [7] It's estimated that between 1985 and 2018, Canadian farmers generated nearly $1.5 trillion in gross farm revenue, but kept only 5% in realized net income [31] as the remainder was captured by agribusiness input companies, banks, etc.

A few reasons have been proposed for increasing farm costs. First, many farmers have achieved revenue increases by adopting methods that depend on costly inputs including energy, fertilizers, pesticides and increasingly complex machinery. [7] Additionally, rising farmland prices impacted farm incomes for those who have had to purchase land. This is especially true in BC, where farmland values are the highest in the country, especially in the Okanagan, South Coast and Vancouver Island. [32]

Technologies with high initial and/or ongoing costs can further push producers' expenses beyond revenues and exacerbate debt. Therefore, the impact of new technologies on expanding farmer debt is a critical consideration for both the solvency of Canadian food production, and the wellbeing of farming families. Based on these considerations, some farming communities have advocated for *"[s]maller scale, farmer-repairable, decentralized technologies"* [33] that are more readily available to farmers across scales, and less likely to exacerbate debt loads.

Social Impacts

Question 3. How might the technology impact consolidation in the food system?

The Canadian food system is increasingly consolidated as larger portions of the market for agricultural inputs, grocery retail, meat processing and other components are dominated by fewer firms. Some have said that Canada has the most concentrated food supply chains in the world. [34] For example, five companies control 80% of the grocery retail market [35], one firm controls more than 40% of Canada's ammonia and urea markets [36] and four firms control over 80% of Canada's federally inspected beef processing [37]. Researchers are concerned with the impact of technological innovation on consolidation in the agri-food system in several ways.

First, the proliferation of novel, patentable agritech can encourage privatization of different components of food production including seeds, fertility, weed control, machinery, software and data. While patents provide incentives for research and development, widespread adoption of patented technologies can also underpin dependence on, and dominance of, patent-holding firms. The privatization of data from digital agritech has also raised concerns over questions of power, ethics and control. [38], [39]

Third, emerging agritech can create new incentives for mergers and acquisitions. [40] For example, the interactions between genetically engineered herbicide-resistant seeds and their complementary herbicides incentivized the merger of seed and agrochemical companies, such as the 2018 acquisition of Monsanto by Bayer, and the strengthening of "life science" corporations responsible for multiple agricultural inputs upon which many farmers depend. [41] Similarly, emerging digital agritech can promote the consolidation of firms that provide digital software, satellite networks, and data storage and analytics. These dynamics highlight the need to examine consolidation and power dynamics within emerging agritech developments.

Question 4. What might the technology displace?

It is important to consider how the adoption of technologies can displace existing structures and systems including local knowledge, economies, people and land. In some cases, technological adoption has caused large-scale, structural shifts for rural communities and surrounding ecosystems, with notable negative impacts that were either unforeseen or ignored at the time of implementation.

For example, industrial agritechnologies promoted an increase in farm size and yields. But as yields increased, profit margins declined (see Technology Treadmill), displacing many smaller farms that were not economically viable with reduced business margins. As such, industrial agricultural technologies favoured high-input and high output farming, displacing much of the small family farm base that comprised rural economies. [7] Between 1951-2016, the number of farms in Canada has decreased from 480,000 to less than 200,000, while average farm size has increased from approximately 360 acres to 820 acres. [17] While these innovations were not intentionally working to displace farmers, a myopic focus on increasing yields obscured a broader view of the impacts of technological adoption for rural communities. [42]

Question 5. How might the technology impact community health?

Technological adoption in agriculture can have broad implications for the health of communities. This includes those occupationally engaged in growing food as well as society at large who consumes agricultural products. Technologies might make agricultural jobs safer, for example by automating a dangerous activity, or they can introduce occupational hazards, as is the case with the introduction of a number of synthetic inputs.[43] As another example, concentrated animal feeding operations, while increasing the efficiency of meat production, have caused numerous health and safety trade-offs.[44] Of particular concern is the role of these operations in advancing antibacterial resistance. Antibiotics are routinely administered to livestock in confined animal feeding operations to promote growth. It's been estimated that three quarters of all antibiotic use in Canada is for livestock, and 90% of this is administered to promote growth. [45] This widespread non-therapeutic use of antibiotics in industrial agriculture is said to intensify *"the risk for the emergence of new, more virulent, or more resistant microorganisms."* [46]

"Industrial technologies were developed to make production easier, faster, and less costly with little regard for their impacts on farmers, farmworkers, or factory workers— or even whether the final products would actually be better for consumers. The consequences for migrant workers in the fields and confinement animal feeding operations today are little different from the consequences for factory workers in the times of Adam Smith." [10]

While humans are most often the focus of health discussions, it is important to note that industrial meat production profoundly impacts animal health and welfare. Recent data estimates that 900,000 cows, 3.8 million pigs, and 202 million chickens get slaughtered for meat daily. Per capita animal slaughter for meat has almost quadrupled since 1961. The majority of these animals spend their life in chronic distress. The authors of this data note that if there is "even a small amount of ethical significance" attributed to the suffering of animals, the moral implications of this are profound [47].

THE JEVONS PARADOX:

The Jevons Paradox describes the phenomenon where technological improvements in resource use efficiency paradoxically cause overall resource use to increase. While technological improvements can make each additional unit of agricultural production require fewer resources, increases in overall production can negate any resource savings gained through efficiency.

Researchers have documented evidence of the Jevons Paradox in response to efficient irrigation technology [24], efficient on-farm energy technology [25], and agricultural intensification. [26] Because increased resource efficiency at the margin does not equate to resource reductions in the aggregate, each of these innovations is associated with an increase in overall use of water, energy and land, respectively.

The Jevons Paradox highlights how improvements in efficiency are often insufficient to reduce overall environmental pressures, especially within the overarching pursuit of continuous economic growth.

3 APPLYING THE FRAMEWORK

The following profiles provide examples of the concerns and benefits associated with two existing agritechnologies in BC and beyond. We have summarized key concerns and benefits documented in the literature to highlight ongoing discussion, nuance, and existing tensions within agritech development.

These profiles aim to summarize key scientific discourse around agritechnology across areas of ecological, economic, and social importance, and how the proposed framework can help highlight the breadth of considerations for agritech policymaking. The framework has been applied to two agritechnology case studies: glyphosate-based herbicides, an existing technology, and vertical farming, an emergent technology.

"Whether a technology is good, bad, or neutral depends on whose intentions or aims are met and who suffers any unintended consequences. The net effects of a technology, considering both good and bad, is determined not only by whether it contributes to the practical aims of some, but whether it contributes to the betterment of society or life in general"

– John Ikerd [10].

3.1 CASE STUDY #1: Glyphosate-Based Herbicides

An Established Technology

Glyphosate-based herbicides (GBH or glyphosates) are a group of broad-spectrum herbicides that kill plants by blocking a critical amino acid synthesis pathway. Glyphosates were commercialized in the mid-1970s as the primary active ingredient in Roundup ®. Since its first decade of use, GBH use has increased approximately 100-fold. [48] Globally, glyphosates are the most widely and intensively used pesticide, and usage continues to rise. [49] Glyphosates are frequently used in combination with genetically engineered (GE) glyphosate-resistant crops (e.g soybean, corn, cotton), which are marketed as Roundup Ready®.

Glyphosates were introduced as an efficient and safe herbicide to manage weeds, increase yields, and improve farmer profitability while offering environmental and safety benefits relative to other herbicides. It was believed to be a "once in a century herbicide" as it was extremely efficient and much less toxic to humans and animals than existing chemical alternatives. [50] However, more recent research suggests that glyphosates are more toxicologically and ecologically harmful than previously assumed. [51] Additionally, the rates of application are rising, and the timing of use has changed since the development of genetically engineered resistant crops in the 1990s. While glyphosates were initially used to kill weeds before crops emerge, the development of genetically engineered glyphosate resistant crops facilitated post-emergent applications. These shifts, in both quantity and timing, promote higher exposure rates for people and the environment than initially believed. [48] Concerns have sparked considerable scientific, political, and legal debate. [48], [52], [53], [54]

GLYPHOSATES—*Applying the Framework*

ECOLOGICAL

1. How might glyphosates impact ecosystem integrity and biodiversity?

BENEFITS

Habitat and biodiversity

- Glyphosate packaged with GE seeds facilitate no-till agricultural systems to improve soil health and reduce on-farm machinery use [55] and associated greenhouse gas emissions [56]
- Glyphosate replaced the use of more ecologically harmful and toxic herbicides

CONCERNS

Habitat and biodiversity

- Glyphosates are becoming less effective as weeds develop resistance. [50] As of 2021, 48 species were reported to have evolved glyphosate-resistance [66], promoting a positive feedback of increased herbicide applications and increased resistance. [67]
- Applications of glyphosates have been overlooked as a source of phosphorus loading in agricultural watersheds [57], contributing to toxic algal blooms and shifting microbial community structures in freshwater from glyphosate-sensitive green algae and diatoms to glyphosate-tolerant cyanobacteria. [58], [59], [60]
- Studies have shown that glyphosate-based herbicides adversely impact several aquatic organisms, especially when combined with other stressors [61] [62].Additionally, research has flagged regulatory oversight and blindspots to understanding the impact of their widespread application on, insects [63], earthworms [64] and other soil organisms. [65]

Structural shifts in food production

- While glyphosates are relatively less harmful than other herbicides,their widespread adoption in combination with herbicide-resistant crops has facilitated an overall increase in herbicide use and application in two key ways: 1) Reliance on glyphosate and tolerant GE crops has reduced crop rotations, diverse plantings and other non-chemical forms of weed management in favour of strategies solely reliant on herbicides. [65] 2) Growing herbicide resistance among weed species in response to sustained glyphosate applications promotes increasing herbicide use. [68], [69]

ECONOMIC

2. How might glyphosates impact farmer livelihoods and rural economies?

BENEFITS

Farm profitability, net income, and debt

- GBH lower costs for labour-intensive weeding
- GBH can increase yields from improved weed control and facilitate the cultivation of larger areas of uniform crops. [55]

CONCERNS

Farm profitability, net income, and debt

- While glyphosates have become a relatively low-cost input, their rising use establishes additional, increasing input costs by necessitating the purchase of both herbicides and resistant GE seed (Roundup Ready ®).

SOCIAL

3. How might glyphosates impact consolidation in the food system?

BENEFITS

CONCERNS

Privatization and market consolidation

- Intellectual property rights privatize genetically engineered seeds, such as glyphosate resistant seeds, and have restricted the ability to save seeds.[41] . Consequently, researchers note that seeds for many staple crops have transitioned from being a public resource to a private one over the course of approximately 75 years. [41], [70]
- Assemblages of genetically engineered herbicide-resistant seeds and their complementary herbicides provide incentives for the merger of seed and agrochemical companies. [40]

4. What might glyphosates displace?

BENEFITS

More harmful and toxic herbicides

- GBH initially displaced the use of more ecologically harmful and toxic herbicides

CONCERNS

Alternative weed management methods

- The reliance on glyphosates for weed management has reduced non-chemical weed management methods including crop rotations and diverse plantings, as well as the local knowledge to implement these effectively. [65]
- Corporate concentration within agribusiness suppliers works to stabilize glyphosate's dominance by reducing incentive for the development of alternative pest control innovation, despite emerging ecological and health concerns [71]. As food system researcher Jennifer Clapp explains "... input companies have not invested in alternative weed control technologies because doing so was less profitable than relying on glyphosate." [40]

5. How might glyphosates impact community health?

BENEFITS

Farmer workers and rural communities

- Glyphosates are reported to be the least toxic broad spectrum herbicide available [50], and a number of researchers have concluded that "under present and expected conditions of use, Roundup herbicide does not pose a health risk to humans." [72]

CONCERNS

Farmer workers; rural communities; general population

- The incidence of non-Hodgkin Lymphoma (NHL) has nearly doubled in the U.S. between 1975 and 2013. [73] A 2019 meta-analysis investigated the association between high cumulative exposures of humans to GBH and increased risk of NHL and concluded that there was "a compelling link between exposures to GBHs and increased risk for NHL."[1] [74]
- In 2015, the World Health Organisation's International Agency for Research on Cancer re-classified glyphosate as "probably carcinogenic to humans" i.e. Group 2A [75]
- There are growing concerns about the health impacts for agricultural workers who are exposed to GBHs and for the broader public who is exposed to increasing residue levels on food as GBH use proliferates. [48]

[1]A number of industry funded studies have challenged those that have found risks associated with glyphosate. [52] For example, a 2023 literature review refuted links between GBH exposure and NHL. The study was funded by Bayer US - Crop Sciences.

3.2 CASE STUDY #2: Vertical Farming
An Emerging Technology

While interpretations of vertical farming vary, this case study focuses on multilayer plant production in a highly controlled indoor environment independent of sunlight and other outdoor conditions. [76] This type of indoor growing aims to control all environmental factors to optimize plant production including light, temperature, humidity, carbon dioxide concentration, water, nutrients etc. Typically, vertical farms use hydroponic systems to deliver and recirculate mineral nutrients and water to plants, which are placed in a growing medium such as peat, sand, wood fibre etc. [77]

Vertical farming is being advanced with the stated advantages of increasing the efficiency of agricultural inputs, augmenting the profitability of food production, and facilitating food production in climatically challenging situations, such as growing off-season or in regions experiencing climate-related challenges to soil-based agriculture. [77] While some have focused on the per unit efficiency opportunities of vertical farming and the capacity to grow fresh produce in otherwise inhospitable conditions [78], others have raised concerns over the aggregate impacts of resource consumption, displacement and privatization. [79] [80]

VERTICAL FARMING—*Applying the Framework*

ECOLOGICAL

1. How might vertical farming impact ecosystem integrity and biodiversity?

BENEFITS

Habitat and biodiversity

- Hydroponic systems can greatly reduce the run-off and leaching of nutrients. The leaching of nutrients from synthetic fertilizers is a major driver of freshwater ecosystem degradation across Canada and globally. [77]

Resource consumption

- The use of hydroponic systems can reduce water use per unit production by capturing and recirculating nutrient solutions. [77], [78]

CONCERNS

Resource consumption

- Vertical farming systems are highly energy intensive as they replace sunlight, a renewable source of energy, for artificial energy and increase the need for heating, ventilation and cooling systems. [80]
- Vertical farms, perhaps counter intuitively, increase the land use required for food production. While multilayer crop production increases the yield per area, full life cycle assessments have found that the overall land footprint of vertical farming is greater than comparable soil-based agriculture and greenhouse operations. This is primarily due to the large amount of electricity production, and the associated land, required to replace sunlight with artificial lighting and control indoor climates for growing. [77]
- The high energy demands of vertical farms increases the greenhouse gas emissions of associated food production. [80] Some have suggested that this can be mitigated by using renewable energy sources. [77], [80], [81] However, this is met with skepticism as it is unsubstantiated that future renewable energy sources would have the capacity to sustain widespread adoption. [81]

ECONOMIC

2. How might vertical farming impact farmer livelihoods and rural economies?

BENEFITS

Farm profitability, net income, and debt

- Vertical farming can facilitate year-round production through artificial indoor growing systems
- Positioning indoor growing systems in proximity to consumers can reduce costs associated with transportation and shipping. [82]

CONCERNS

Farm profitability, net income, and debt

- Start-up costs for vertical farms are prohibitively high. The start up costs per area of cultivation have been estimated to far exceed those of high-tech greenhouses. [83]
- The operating costs of a vertical farm are also high, primarily due to the energy costs of replacing sunlight with artificial lighting and the need for heating, ventilation and cooling systems. [78]

SOCIAL

3. How might vertical farming impact consolidation in the food system?

BENEFITS

CONCERNS

Privatization and market consolidation

- Vertical farming systems require significant financial commitments to establish and maintain. Therefore access is limited to those with extensive access to capital, increasing the role of private investment and financialization in food production. For example, one vertical farm in BC reported that starting their operation costs millions. [84] Ventures of this nature have the potential to shift food production and farmland from farmers looking to support themselves through farming businesses, to investors seeking (often increasing) returns from their investments in food production.

4. What might vertical farming displace?

BENEFITS

CONCERNS

Agricultural land

- The compaction and paving of agricultural land irreversibly erode its capacity for soil-based agriculture. Therefore, the placement of agricultural operations that do not require arable land is important for maintaining BC's capacity for soil-based agriculture.

Local knowledge and economies

- Vertical farming operations can displace land-based practices, relationships, knowledge and jobs. There are concerns that emerging agritech innovations, such as vertical farming, are "intended to serve farmers to some extent by replacing them". [42]

5. How might vertical farming impact community health?

BENEFITS

General Population

- Vertical farms have the potential to increase food safety for suitable crops by eliminating the need for herbicides and pesticides in highly controlled environments. [77]
- Vertical farms can improve access to fresh produce in communities that otherwise face barriers, such as Northern communities. [77]

CONCERNS

General Population

- Due to the high production costs, vertical farming is currently limited to rapidly growing plants, with high portions of salable parts, such as lettuces, herbs, etc., [85], [86] which provide limited calories and nutrients. Current vertical farming excludes nutrient dense staples foods. One study estimates that even if LED technology reaches maximal efficiency in the future, the cost would still preclude the production of many vegetables and staple crops such as wheat, rice, and potatoes. [85]

WHAT ABOUT "LAND SPARING"

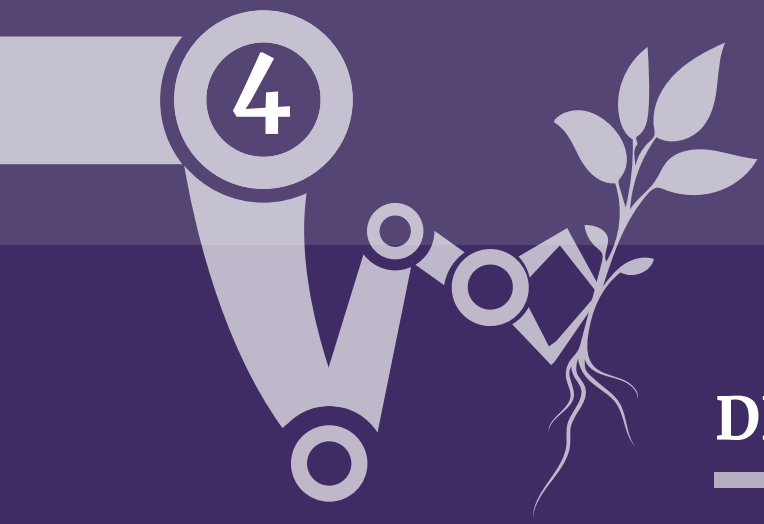
Proponents of intensive indoor growing systems often advocate that these technologies significantly increase food production per area, reducing the overall need for arable land and thereby indirectly facilitating habitat restoration. The assumption is that unneeded agricultural land can then be converted to more natural habitats. This argument is often referred to as "land sparing." Critics respond with three primary concerns. First, indoor growing is best suited for a small selection of non-staple crops such as salad greens, strawberries and herbs. Staples crops are not conducive to these systems, making indoor growing an unsubstantiated substitute for soil-based agriculture. Second, when land requirements for energy production are considered, researchers have found the footprint of vertical farming is greater than soil-based agriculture. And finally, even if the latter were not the case, given the economic incentives to increase production, the absence of policy addressing the scale of food production, and land use competition in agricultural areas, increased intensification or yields/acre have not resulted in increased natural habitat through land sparing. [25] Therefore it is critical that policymakers consider and address the direct impacts of agriculture and agritech on habitat quality and biodiversity, rather than assuming theoretically that indoor growing systems facilitate habitat restoration elsewhere through land sparing.

"Just as increasing production does not guarantee alleviating hunger, technologies make land (and biodiversity) savings possible, but realizing them depends on bold political decisions."
– Pellegrini and Fernández [25]

FAMILY FARM VS AGRIBUSINESS VENTURE

A note about profits vs returns on investment

All businesses need to make a profit, whether they are owned by an individual family or by a consortium of investors. However, these two ownership structures have different implications for the operation and decision-making on farms. Family-owned businesses seek profit as a source of livelihood. The goal of these businesses is likely to earn enough profit to support a dignified and healthy life. A family business would likely be satisfied with earning relatively the same amount of profit each year provided it is sufficient to meet their needs for living, saving, etc. Investment capital, however, pursues agriculture as a business venture, likely with the expectation that profits will continue to increase. Investors seeking returns on their investments will likely require a continuous growth in profits to achieve the desired minimum percentage of returns. These two business structures can incentivize different on-farm decisions. For family farmers, farming is a long-term investment and sometimes an intergenerational livelihood, motivating actions whose benefits might not materialize for many years, or even generations. For agritech investors, the need to sustain relatively short-term growth can motivate extractive behaviours for the benefit of short term, increasing profits.



4 DISCUSSION

Emerging technologies present a number of opportunities to improve efficiencies in agriculture and help address ongoing challenges in the sector. However, there is a need for thoughtful policy development to support the benefits of agritech adoption while preventing adverse ecological, social and economic impacts. Technology is an important tool, but it is not a silver bullet solution to agricultural challenges, nor a replacement for human thinking and thoughtful policy. In this light, we present three overarching principles to help center the public interest and guide policy decisions for agritech development and implementation.

1 Innovation is a value-based process, and governments have a democratic mandate to inform and direct its evolution in the public interest:

Contrary to much of the mainstream discourse, innovation is not an objective technocratic process.[42] The innovations that we pursue will continue to restructure our communities and societies, with both benefits and risks.

Since private corporations have a mandate to maximize profits, their research and development agendas for agritech are not necessarily compatible with the public interest. There are concerns that agritech innovations will disproportionately benefit large agribusiness enterprises who are driving the agritech research and implementation agenda according to narrow private interests. [3], [4] As such, the government has a democratic mandate to establish an agritech agenda that benefits society at large, and sets the conditions for sustainable and equitable agritechnology. [42] Here, "responsible innovation" research provides guidance by recommending participatory and deliberative processes for addressing agritech concerns. [42], [87] Importantly, these processes should target those who have been historically excluded or marginalized in innovation decision-making. [42] The framework presented in this discussion note can further guide participatory processes by highlighting critical questions to assess and address agritech benefits and concerns.

Agricultural economist John Ikerd offers two guidelines for agritech development.

1) "The adoption of a new technology should not force others to do likewise, but instead allow others to freely choose either to use or not use it."

2) "a technology should reduce human drudgery but should not replace human thinking." [10]

2 Agritech adoption should center the public interest and steward farmer autonomy while preventing farmer displacement:

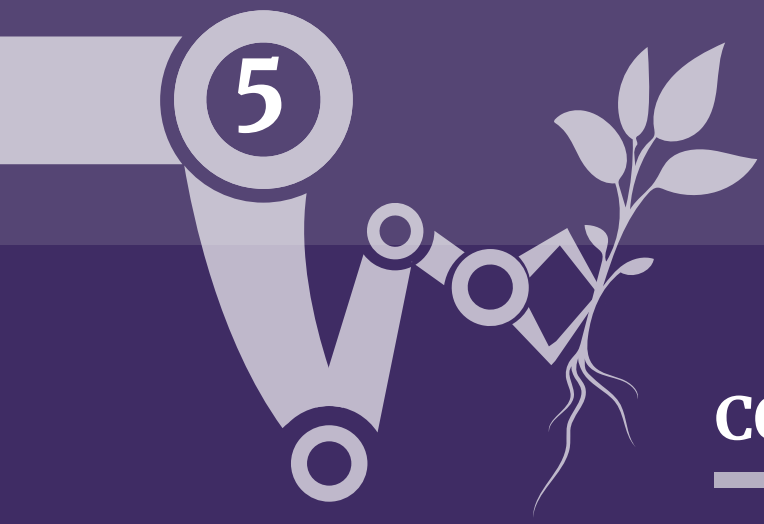
There are concerns that emergent agritech innovations are positioned to further concentrate power and control in the food system by increasing the privatization of farm inputs, processes, and knowledge, and by further promoting consolidation among the large agribusiness firms that are positioned to provide these.

As discussed, we can learn from the proliferation of industrial agricultural technologies, such as synthetic fertilizer and pesticides, which have had a significant impact on farmer autonomy, farm operating costs, farm consolidation, rural communities and rural ecologies. Digital agriculture technologies, as one example, have the potential to reinforce consolidation in the food system by increasing the dependence of agriculture on proprietary software and data provided by a small number of private agribusiness firms. Additionally, costly agritech is likely to exacerbate farmer debt and provide disproportionate access to large, capital-intensive farms, Similarly, there are concerns that emerging agritech innovations, such as vertical farming or precision agriculture technology, are *"intended to serve farmers to some extent replacing them"* with mechanization and a workforce that specialized in data and technology skills.[42] Here, policymakers have the responsibility to ensure that agritech is accompanied by supportive policy frameworks that can maintain the public interest by preventing market concentration, supporting technology access across farm scales, and safeguarding against the displacement of farmers and farming communities.

3 Technological innovation is not a silver bullet solution and must be accompanied by policy to achieve ecological, economic, and social goals:

Technology has and will continue to help advance our social, economic, and ecological goals. However, technology should be accompanied by thoughtful policy to enable the benefits of innovation while preventing harm.

For example, automation or mechanization can help reduce exposure to dangerous or otherwise undesirable work. However, it is not a substitute for a policy environment that facilitates desirable working conditions and decent pay in the agricultural sector. Similarly, several agritechnologies can make reductions in resource use possible by using land, water, fertilizer, and other inputs more efficiently. However, technological efficiency is not a substitute for thoughtful policy to integrate agricultural activities with ecosystem capacity, ensure habitat protection for biodiversity, promote healthy, living soils, restore wetlands and build continuity between economic and ecological goals. As a final example, digital technologies may provide improvements for a diversity of farmers, but, should they proceed, they must be accompanied by proper governance and policy frameworks to ensure equitable access and ethical data practices. [5]



5 CONCLUSION

In conclusion, this discussion notes aims to promote policy makers to

- **Consider a broad range of outcomes, looking beyond the most immediate efficiency-based arguments for agritech implementation.** This discussion has provided several examples where a myopic focus on efficiency has, and can continue, to bring detrimental social, ecological and economic trade-offs for farmers and rural communities.
- **Understand, anticipate, and mitigate structural shifts in food production that undermine the benefits of innovation.** This discussion note includes several examples of large-scale transitions that have had notable harmful trade-offs.
- **Seek broad input from the farming community on the utility, impacts and desirability of agritech proposed agritechnology.** The interest of agribusiness corporations, venture capital, and technology investors are not necessarily compatible.

As we are at the onset of a new wave of technological innovation in agriculture, we have a critical opportunity to learn from our shared history and promote technological adoption that is ecologically, economically, and socially beneficial to farmers, farming communities and the ecosystems that support us.

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