Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 23 April 2024
DOI 10.3389/fsufs.2024.1358515

Check for updates

OPEN ACCESS

EDITED BY
Li Xu,
University of Saskatchewan, Canada

REVIEWED BY
Viswanathan Pozhamkandath Karthiayani,
Amrita Vishwa Vidyapeetham (Amritapuri Campus), India
Oscar Ortiz,
International Potato Center, Peru

*CORRESPONDENCE
Charlotte Potter
✉ potterc@uoguelph.ca

RECEIVED 19 December 2023
ACCEPTED 29 February 2024
PUBLISHED 23 April 2024

CITATION
Potter C, Sarapura-Escobar S, VanderZaag P, Salari D and Zink R (2024) Best management practice adoption amongst potato producers in Ontario: a study of drivers and barriers. *Front. Sustain. Food Syst.* 8:1358515.
doi: 10.3389/fsufs.2024.1358515

Best management practice adoption amongst potato producers in Ontario: a study of drivers and barriers

Charlotte Potter[1]*, Silvia Sarapura-Escobar[1], Peter VanderZaag[2], Danial Salari[1] and Regan Zink[1]

[1]School of Environmental Design and Rural Development, University of Guelph, Ontario College of Agriculture, Guelph, ON, Canada, [2]SunRISE Potato, Alliston, ON, Canada

Best management practices (BMPs) are practical, affordable alternatives to conventional production systems. They contribute to improving the agricultural production system's ability to address social, economic, and ecological challenges. BMPs enhance the viability and sustainability of agriculture when successfully applied, but in systems where intensive industrial agriculture predominates, their use is limited. Working with potato producers (large, medium, and small scale) in South-Western and Central Ontario, Canada this project applied a Systems Thinking approach to understand motivating drivers and structural, institutional, and organizational barriers impacting the adoption of BMPs for potato cultivation. This study used a mixed-methods approach for two years to collect quantitative and qualitative data using a farm-level survey, focus groups, workshops, and participant observation. Data was collected regarding demographics, management approaches, social networking, and perceived challenges with BMPs uptake. Our data analysis revealed that family and future generations, ecosystem, soil and human health, community and social relationships, and efficiency and profitability were motivating drivers (based on beliefs and values) influencing management decisions. However, structural, institutional, and organizational barriers (including market access, regulation, production efficiencies and competition), mediate producers' abilities to act according to these motivations. Small-scale, medium-scale and large-scale producers are impacted by these barriers differently. In understanding the decision-making factors which drive BMP uptake in Ontario's potato sector, policy and program design can leverage drivers and reduce barriers.

KEYWORDS

best management practice, behavioral change, sustainable agricultural management, systems thinking, Potato production Ontario

1 Introduction

Agricultural production involves the exploitation of resources such as soil, water, end energy to produce food and fiber (De Vries et al., 1995; Bommarco et al., 2018). Agriculture is a comprehensive term used to describe the methods through which crop plants and domestic animals provide food and other products (Harris and Fuller, 2014). These production systems are heavily impacted by global climate change (Adopted IPCC, 2014). Elevated CO2, increased temperature, changes in precipitation, increased frequency of extreme weather events and the emergence of new weeds, pests, and pathogens impact agricultural practices and put increasing strain on producers who manage agricultural production systems, including farms (Lobell et al., 2011; Altieri et al., 2015). A farm is an area of land used for growing crops, or keeping animals which might be maintained for subsistence or profit (Garner and De la O Campos, 2014). Agricultural production is highly controlled and involves the use, manipulation, and control of ecosystems in which plants are produced, which in turn alters the natural environment (Aydinalp and Cresser, 2008; Harris and Fuller, 2014). Given these characteristics of agriculture, even low-intensity productive systems are environmentally disruptive, but these impacts increase with the intensification of high-yielding crop variety use, fertilization, irrigation, pesticide and herbicide use (Matson et al., 1997; Xu et al., 2021). As the demand for food increases alongside the global population, many agricultural production systems intensify unsustainably, causing increasingly disruptive environmental impacts and degradation including loss of animal habitats and biodiversity, nutrient runoff and watershed pollution or sedimentation, pesticide poisoning, desertification of landscapes (Zhang et al., 2007; Power, 2010), and CO2 emissions leading to climate change (Aydinalp and Cresser, 2008).

Recognizing the co-constitutive relationship between agricultural production and climate change, innovations including the adaptation of appropriate management solutions which address the negative impacts of agriculture is critical to maintaining the ability of these ecosystems to continue to function (Power, 2010).

In Ontario, potato producers confront multiple challenges resulting from climate change pressures (Bryant et al., 2000; Wall and Smit, 2005; Gouvernement du Canada, 2020), the impacts of COVID-19 on supply, demand, and negative impacts on value chains (Richards and Rickard, 2020), and the rising cost of production, fuel and chemical inputs (Government of Canada, 2022). Best Management Practices (BMPs) are practical, affordable approaches to agricultural production systems that aim to conserves soil and water resources while maximizing yield, productivity or quality (Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2021; Ahmad & Sharma, 2023) which provide farmers with potential solutions to these multiple and ongoing challenges. While BMPs represent environmental, economic, and socially sustainable solutions to production challenges, research suggests that there are significant barriers for farmers in accessing, adopting, and adapting these alternative management approaches (Karali et al., 2014; Miller, 2014; Weber and Alberta, 2017; Liu et al., 2018).

In order to strengthen farmer capacity for implementation or uptake of BMPs for sustainable resource management, it's important to first understand the primary motivating drivers that influence farm management decision-making. However, farmers also face structural, institutional and organizational challenges that must be overcome for individuals to apply BMPs, creating barriers to adoption (Feola et al., 2015; Kuehne et al., 2017; Fielke et al., 2018; Rose et al., 2018). Identifying and understanding these barriers to BMP use is a necessary next step for improving BMP implementation and uptake. Lastly, understanding farmers' existing or potential capacities (social, technical, organizational) which may support BMP uptake may inform development of more supportive policies which build on the existing strengths for different groups of farmers (Eakin et al., 2014; Miller, 2014;).

Heterogeneity among farms requires diverse interventions to target different management approaches. Understanding farmers' diverse activities and resource use can provide important insights regarding behavior-driven decision making related to BMPs implementation. It may also improve attempts to create an enabling environment which better facilitates the implementation or uptake of BMPs. This paper presents preliminary findings from a three-year study with potato farmers in South-Western and Central Ontario. More specifically this paper aims to identify the key drivers of BMP adoption among potato producers in Dufferin County, County of Essex, Gray County, Simcoe County, and Timiskaming District by focusing on existing cases of strong multi-dimensional farm performance.

Our research question for this project asks, what are the strongest influences impacting behavioral changes related to BMP adoption, and what are the key drivers behind decision making leading to behavior change? To address our research question, this paper will examine how diverse conceptualizations of sustainability combined with differences in farm characteristics, influence farmers' use and uptake of different BMPs. This paper is divided into 5 sections. Section one provides a brief overview of contemporary research related to motivational drivers for the use and uptake of BMPs, as well as information on the context of potato cultivation in Ontario included definition of key terms. Section two, materials and methods, outlines the theoretical and analytical approach guiding this study and the tools and methods used for data collection. Our conceptual framework blends systems mapping with discourse analysis and the tools used in this study include a literature review, farm-level survey, focus group discussions, semi-structured interviews, field-visits and participant observation. Section three presents the results of this study outlining findings from the farm-level survey complemented by qualitative findings. Section four offers an analysis of findings, outlining how beliefs and motivations, structural, institutional and organizational factors, and perceptions of sustainability drive BMP use and uptake.

This paper shares our preliminary findings and discusses the significance of results emerging from interactions with diverse small-scale, medium-scale and large-scale farmers throughout the Ontario Potato Sector (OPS). The results of the research are of interest to farmers, research, extension services, planners, municipalities, Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), and national governmental institutions. While findings from this study will be specific to the potato production systems, the methodology, approach, and typologies can support and inform research looking at other agricultural systems.

1.1 Current research overview: motivational drivers for the uptake of best management practices

A growing body of literature aims to examine farmers' motivations and attitudes surrounding the use and uptake of farm management approaches, including BMPs (Liu et al., 2018; Mozzato et al., 2018). Traditional research on decision-making factors for BMP adoption by farmers focused on the structural characteristics of farms (including farm size, degree of fragmentation, land tenure, proximity to urban centers) and socio-demographic characteristics of farmers, while newer research has begun to examine how beliefs and attitudes influence motivations and adoption decisions (Mozzato et al., 2018). There is also growing interest in understanding processes of behavior-change in supporting the adoption of sustainable management approaches (Yiridoe et al., 2010; Weber and Alberta, 2017; Rose et al., 2018; Dessart et al., 2019). It is interesting to note that sustainability is defined inconsistently throughout the literature. D'souza et al. (1993, p. 159) define sustainable agriculture as any system involving "the continued or increased use of a combination of appropriate practices or technologies". Dessart et al. (2019), p. 419) alternatively define it as "farming practices whose main expected benefit – relative to conventional practices – is the provision of positive externalities on biodiversity, water, soil, landscapes and climate change". For Dumanski et al. (1998), 'sustainability' is meaningless without indicators and measurements of success to track the performance of agricultural production systems, which calls for specific definitions and conceptualizations of progress towards sustainability. Based on this, individuals' definitions of sustainability impact their measurements of success or the utility of an approach (e.g., adoption of BMPs). Alternative practice use is mediated by the degree by which BMP implementation is evaluated positively or negatively by farmers which may be shaped by subjective beliefs about relative ease, utility or value associated with adoption, or social pressure to adopt, past experiences, or individualized constraints (Campbell et al., 2014; Bijttebier et al., 2015). Rose et al. (2018) argues that attitudes and beliefs do not always align with behaviors; instead, a value-action gap exists between cognition and behavior. For Rose et al. (2018) behavioral approaches put too much emphasis on individuals, without accounting for the irrationality of actions. Similarly, Kanter et al. (2018), p. 84) argue that scientists "assume that decision-makers will automatically apply whatever result is produced by science because of formal logic and reduction of uncertainty that models can provide to the otherwise extremely complex nature of agriculture systems". Campbell et al. (2014) note that 'information deficit models' of BMP uptake which assume that lack of knowledge is the key factor limiting adoption ignore barriers and constraints to practice adoption. In many cases, innovative practices have been known for decades by farmers and other reasons exist which limit their use. Instead, they should understand the trade-offs farmers make in making decisions, and structural, institutional and organizational barriers that are outside of their control which impact their practices. However, Allan et al. (2022) argue that the current emphasis in the literature on identification of 'barriers' to adoption conceal the experiential skills and knowledge held by farmers, and ignores these trade-offs.

Examining trade-offs can offer insights about how value schemas of particular farmer typologies support use or management of ecosystem services (Kragt and Robertson, 2014; Bartkowski et al., 2020; Shen et al., 2020). Dessart et al. (2019) argue that farmers' decisions are primarily business driven. Similarly, Weber and Alberta (2017), states that farmers are often more motivated by environmental and financial benefits impacting their farm directly, as opposed to those supporting the health and sustainability of the whole agroecosystem. Rose et al. (2018) call for improved economic incentives for farmers practicing Integrated Farm Management (IFM) and agroecological farming. While not BMPs directly, IFM considers the use of modern technologies alongside traditional methods to be an approach to best management, encompassing site-specific, continuous improvement across the whole farm (Morris and Winter, 1999), while agroecological farming involves the application of management practices based in ecological principles to agricultural systems (FAO, 2015). Miller (2014) similarly argues that the appropriate use of incentives is key to designing effective conservation programs. Pointing to the vast literature on the impact of financial incentives for BMP adoption, Liu et al. (2018) argue that government subsidies, credits and loans can have great impacts; They discuss 'associated costs' or 'opportunity costs' associated with no-till cropping adoption, where the price of herbicide required for this approach can be a major deterrent (D'Emden et al., 2006; Liu et al., 2018). Direct or upfront costs such as machinery, input, or land purchase can disincentivize BMP adoption if they are perceived to be greater than the economic benefits of adoption (Miller, 2014). Given the immediate capital cost and risk to livelihoods associated with potential loss or reduction in yields, these trade-offs are often temporal in nature. Miller (2014) suggests that for many BMP adopters "costs are accrued in the short-term, the benefits of implementing BMPs may only be tangible in the medium or long-term" (Miller, 2014, p. 14). Lack of cash, credit, or low risk tolerance represent barriers to BMP adoption as well (Karali et al., 2014; Liu et al., 2018). Investment in human labor and time (required for small-scale organic or agroecological operations) also limit farmer uptake, as time spent implementing certain BMPs might result in less time to be spent on other, more profitable, farm tasks (Miller, 2014). At the same time, it is important to consider the incremental and interdependent nature of BMP uptake. Han and Niles (2023) argue that while the majority of BMP adoption literature still considers adoption to be a binary choice (to adopt or not to adopt), in reality, adoption is continuous, gradual, dynamic and complex.

Farm management decisions are not only made by farmers at the level of the farm, but also at the level of household, society, community, nation, government, organizations; The food system context plays an important role in influencing farmer behavior (Weber and Alberta, 2017). Complex vertical relationships established within the value-chain impact farmers' management decisions (Mozzato et al., 2018). Price premiums on certain cash/commodity crops are set by consumer demand and corporate interest, and depend on the infrastructure of processors, retailers, and transporters (Mozzato et al., 2018). Similarly, social capital and social networks can greatly influence behavior as norms about 'good practice' can shape perceptions about the value or utility of farm management approaches (Weber and Alberta, 2017). This may include for example variety selection decisions such as selecting varieties because of their yield or pest resistance or based on the preferences of consumers, or marketing decisions determining whether to participate in niche or local markets, or in larger or wholesale markets. Relationships and social networks also factor into decision making for BMP adoption. Yiridoe et al. (2010) suggests that developing trusting relationships between farmers, decision makers, and knowledge brokers may impact the use and uptake of BMPs, and argue that sources and channels of information impact the likelihood of practice adoption. Investment in information and workshops, and formation of strong relationships among actors within the food system and value chain is critical.

1.2 Context: conventional agriculture in Ontario's potato sector

1.2.1 The Ontario potato sector

The Ontario Potato Sector (OPS) represents a diverse mixture of small-, medium-and large-scale producers applying various production and farm management approaches which include conventional, organic and agroecological production systems. These produce potatoes for chipping, processing (chips, French fries, frozen goods), table (fresh) potatoes, and potatoes for seed. Additionally, the production of potatoes for potato starch is a small but emerging market. The different end use and consumption of potatoes will determine which variety is grown and which production system is required, which will in turn influence which markets channel a farmer can access to sell their products. For example, potatoes produced for chipping tend to be grown by large-scale, conventional producers, with some medium-scale conventional and organic farmers also supplying to this market. Because of the industrialized nature of the potato chipping process, and the buyers requirements, potatoes grown for chipping must be uniform in size and shape (to ensure consistency and suitability with mechanization), with specific sucrose and glucose levels (to optimize their ability to fry) which are developed and maintained after harvest using storage technology (including ventilation, CO2 and temperature regulation) (Kumar et al., 2004). Because of the industrialized nature of chip processing, chipping potato production favors economies of scale and the use of conventional, intensive farming methods, which are more readily accessible to farmers with greater access to capital, technology, and land. Because the majority of potatoes grown in Ontario are produced for chip processing using conventional farming methods, the sector is dominated by a small percentage of large-scale intensive operations (Agri-Food Canada, 2021).

Conversely, potatoes grown for table (fresh) consumption are produced by farmers of all sizes (large, medium, small) and production systems (conventional, organic, agroecological). Farmers may produce for large markets by selling their goods to wholesale distributors, or supply to smaller markets through restaurants or direct-to-consumers. Similarly, large, medium and small-scale farmers grow seed potatoes (tubers which are sold as seeds), but the percentage of cultivators is more limited with roughly 20 farms producing seed potatoes (Ontario Seed Potato Growers Association, 2023). There are also a small group of potato starch producers, but their number is unconfirmed as, unlike the Ontario seed potato growers (OSPGA), they do not have an association.

1.2.2 Conventional potato production

Government subsidies and protections for specific crops, liberalization of markets and privilege of free-trade mechanisms in the agri-food industry puts pressure on producers to engage in specialized production (Rotz and Fraser, 2015). Increased specialization has supported the rise and dominance of large-scale, industrialized agriculture (Bradshaw, 2004). Conventional potato production in Ontario is characterized and can be defined by large-scale, high-intensity production, Ontario's potato production system depends on intensive substitution and input use (fossil fuels, agrichemicals, fuel); industrial, mechanized, standardized processes, and sale and distribution of goods to a small selection of corporate buyers (wholesale retailers, processors) (Campbell et al., 2014; Agri-Food Canada, 2021). Oriented around productivity and growth, conventional industrial agricultural systems, including but not limited to potato production, use technologies and economies of scale for efficient production of high quantities of food for local and global markets (Cloke et al., 2001). However, replacing natural systems functions with substitutions to address challenges (e.g., pests, weeds, soil fertility), and technocratic, industrialized processes have been linked to the propagation of more resistant and aggressive pests, soil and water contamination, and public health concerns (Kremen and Miles, 2012; Brzezina et al., 2016). In Canada and the United States, specialization and industrialization of most agricultural sectors has also been linked to rapid decline in crop diversity, which measures the value and range of functional traits within an ecosystem (Fragoso et al., 1997; Matson et al., 1997; Tilman, 1999; Tilman et al., 2001, 2002; Tscharntke et al., 2005; Plummer et al., 2008; Rotz and Fraser, 2015; Goswami et al., 2017). For potato producers, subsidies, long-term contracts (locking farmers into producing pre-determined varieties up to ten years in advance), and protections for specific crops make it more difficult for producers to change their crops or varieties, even in the face of climate and/or market volatility. Prevalence and severity of extreme weather events, droughts, flooding, pest and disease outbreaks (including Late Blight, alternaria, soft rots, botrytis and white mold, etc.) has increased nationally and internationally, so that farmers reliant on conventional applications or limited crop portfolios have been left struggling to maintain productivity and profitability amid changing climate conditions (Rotz and Fraser, 2015).

Small-and medium-sized, diversified, non-conventional producers do exist, but the consolidation of the OPS has led to a dramatic decrease in producers, from 243 farms in 2006, to 147 in 2016 (Agri-Food Canada, 2021). Rising land and production costs driven by urban encroachment and rising fuel costs have driven this consolidation as smaller, family farms became less viable under increased financial pressure (Eisenhauer and Mitchell, 2011; Blais et al., 2021). The sector's orientation towards conventional and large-scale production threatens small-and medium-scale producers of all production approaches and decreases the likelikood of BMP adoption. The North American agri-food system is controlled by a small number of rich, transnational, oligopolistic corporations which are able to exert significant power over the market and control the value chain (Rotz and Fraser, 2015). By controlling markets, these corporations pressure producers to participate in value chains, and set specific standards or regulations for production which are a requirement for participation—whether or not it is beneficial to the producer (Fulponi, 2006; Karali et al., 2014; Rotz and Fraser, 2015). Smaller farms who are unable to meet corporate standards and regulations (due to lack of resources, time, capital) are then forced to sell their farms or leave the sector (Fulponi, 2006; Rotz and Fraser, 2015).

1.2.3 What is the role of BMPs?

BMPs for sustainable production are associated with reduced chemical or inorganic fertilizer and pesticide use, agrobiodiversity stewardship, improved soil health and preservation of soil organic materials (Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2021). However, as a result of diverse contextual realities, *in-situ* challenges, and specific needs of individual farmers, there is variation and diversity associated with BMP use. Diverse geography, size, resource access and styles of production will influence which BMPs are best suited (Yiridoe et al., 2010). This paper considers the full array of BMPs, as defined and articulated by participant farmers, outlined by OMAFRA, and referenced by the OPB. These include reduction in chemical inputs (for economic efficiency, soil health, and human health benefits), diverse applications of cover crops and crop rotations to ensure constant soil coverage and reduce instances of erosion and nutrient loss caused by bare soils, reduced tillage to reduce GHG emissions and erosion caused by repeated soil disruption, and seed and varietal selection for climate suitability, pest or disease resistance, heartiness and consumer preferences.

2 Materials and methods

2.1 Theoretical approach

This research examines how the social, economic, and environmental context of the OPS influences the adoption of alternative and sustainable Best Management Practices (BMPs) by small-, medium-and large-scale farmers with diverse production styles to adopt. Our research used a Systems Thinking (ST) approach to understand the complexity of factors influencing producers' uptake of BMPs. This study also applied Discourse Analysis (DA) to analyze our findings. These complementary approaches shaped the research design and analysis of results.

2.1.1 Systems thinking

This study applies a Systems Thinking (ST) approach to investigate interactions and links between actors and components in human, social and natural systems which produce emergent patterns, properties, and behaviors (Meadows, 1999; Levy et al., 2018). In the context of food systems, ST examines the widespread, complex, multifaceted, interconnected nature of food systems, to understand underlying, root causes of decision-making factors (Ha et al., 2016). A "system" as defined by Meadows (2008, p. 188) is a "set of elements that [are] coherently interconnected and organized in a way which produces a pattern of behaviors over time." By exhibiting "emergent properties" or functions, this set of elements becomes greater than the *sum of its parts,* making it a system (Posthumus et al., 2018, p. 9). ST studies systems holistically and relationally (Monat and Gannon, 2015), to expose "leverage points for systemic change" (Posthumus et al., 2018) and find new approaches to complex problems (Hubert and Ison, 2017). Leveraging ST, this study identifies drivers and barriers influencing BMP uptake, demonstrating how macro-level structural, institutional and organizational barriers differently impact productive practices of potato producers, and highlighting leverage points for systemic change.

2.2 Conceptual framework

In order to identify leverage points for systemic change, this study first aimed to identify the elements, relationships and emergent patterns present within the system of interest which in this study is the Ontario Potato Sector. Investigating BMP use and uptake, the study focuses on factors and relationships that influence this outcome or system function. The elements identified within our system of interest fall into three categories of analysis: organizations (social networks, corporations, governments, associations), institutions (rules, regulations, norms) and structures (patterns of events or behaviors that are relatively stable over time). These elements relate to each other in unique ways depending on the resources (skills, capital, land, influence, time) that each actor has available to them. Given the research focus on farmers' adoption of BMPs within the sector, these mediating resources were delineated according to the size of different farms. Clustering participants by size, the boundaries of each sub-system were determined based on the physical land each group had available to them, which is an indirect indicator of market participation, management approach, and income, and available land-based resources. At the same time, we consider the 'openness' of each of these systems, as they operate together and influence one another.

Applying a systems thinking analysis approach to identify systems elements (organizations, institutions, structures), and relationships between them (differentiated based on resources defined by farm-size), this study then used systems mapping software to visually identify which 'nodes' or elements were most influential in impacting the ability or likelihood of BMP adoption for each group, and understand what feedback loops exist with each sub-system which increase the strength and persistence of each node.

2.3 Methods

Using a mixed-methods approach, this study collected and triangulated quantitative and qualitative data regarding farmer demographics, management approaches, social networking and perceived challenges with BMP uptake using a farm-level survey, focus groups, workshops, and participant observation. First, a systematic literature review and policy scan was conducted, highlighting key aspects related to the uptake and use of BMPs amongst farmers in a range of contexts and sectors. This supported the development of the farm-level survey which was conducted with producers from across the region to collect quantitative participant information. Following the survey, the research team collected qualitative data through semi-structured interviews and participants observation conducted over the course of 2 years across 3 field-visits, 3 farmer field-days, 1 workshop, 3 organizational meetings, and several informal gatherings.

2.3.1 Research scope

Research was conducted with small-, medium-and large-scale potato producers in five regions in Ontario, including: Dufferin County, County of Essex, Gray County, Simcoe County, and Timiskaming District. These regions were selected due to the higher number of potato producers located in these areas. While there are few potato producers operating in more northern districts in Ontario including the Muskoka and Sudbury area, the majority of producers are concentrated in the selected regions. Activities were supported with in-kind support by Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), the Ontario Potato Board (OPB), the Ecological Farmers' Association of Ontario (EFAO) and Ontario Soil and Crop Improvement Association (OSCIA). A Snowballing Approach was applied to leverage existing relationships with key stakeholders and informants in each farmer typology to identify additional participants. The Snowballing Approach is a method of recruitment whereby participants are engaged through reference from one person to another (Streeton et al., 2004), "quickly building up and enabling the researcher to approach participants with credibility from being sponsored by a named person" (Denscombe, 1997).

2.3.2 Participant selection – inclusion and exclusion criteria

Farmers in South-Western and Central Ontario who grow potatoes (including processing [chips, French fries, frozen], fresh [table] consumption, seed) were eligible to participate. Farmers located outside of South-Western and Central Ontario, and those who do not grow potatoes were excluded from our study. Key stakeholders and informants were identified through consultation with our project partners and advisory committee. Identification and outreach to producers was facilitated through our contacts with EFAO, OSCIA and the OPB. Partnering with multiple and diverse farmer-associations contributed to increased scope and diversity of participation. In total, there are 147 potato producers registered with the OPB, the majority of which are located within South-Western and Central Ontario. For this reason, we consider our sample size to be 147.[1]

2.3.3 Literature review

A systematic literature review of five relevant databases (Web of Science, Google Scholar, CAB Direct, AGRICOLA, Agricultural and Environmental Science Collection) and jurisdictional scan of drivers at different levels (e.g., system, organizational, farm, and individual) was conducted to understand how decision making to adopt BMPs is influenced at international, Canadian, and provincial levels. The literature review covered diverse geographical contexts and jurisdictions, demography, and different social, economic and ecological systems to make available different indicators for developing the farm-level survey Ontario Potato Board Membership, 2024.

2.3.4 Survey

A farm-level survey was conducted to provide quantitative information about individual farm and farmer characteristics as well as information on management approaches. Questions were posed regarding respondent's approaches to several aspects of on-farm management, including tillage, fertilizer and pesticide use, and irrigation. BMPs for sustainable agro-ecosystem management commonly identified in the literature focus on the reduction of agro-chemical inputs (Yiridoe et al., 2010; Novita and Ilsan, 2016; Babajani et al., 2023), reduced tillage (Weber and Alberta, 2017; Dessart et al., 2019; Djaman et al., 2022), water conservation (Shock et al., 2007; Miller, 2014; Liang et al., 2019; Government of Ontario, 2022), cover cropping, crop rotation and crop diversity (Dogliotti et al., 2006; Bijttebier et al., 2015; Dessart et al., 2019; Li et al., 2023). For this reason, additional questions were included to capture information regarding use of cover crops, crop rotation and fallowing. Data was also collected about key drivers of decision making and behavioral change. To ensure data reliability, the survey used established metrics and indicators, and followed a standardized and replicable questionnaire format. The survey represents a view of the farm and does not aggregate or integrate information in a causal model based on "average" or "typical" household behavior.

Surveys were distributed online using the survey platform Qualtrics, and in-person at farmer-organization meetings. Initial survey participants were contacted through the Ontario Potato Board and represent potato producers in the province who manage 5-acres or more of potatoes. Surveys were then distributed through the Ecological Farmers Association of Ontario (EFAO) and Ontario Soil and Crop Improvement Association (OSCIA) to farmers who self-identify as producers who grow potatoes (in addition to other crops) and who belong to or are associated with either or both the EFAO and OSCIA. The survey assessed respondents on a variety of variables including A) demographic information; B) farm characteristics; C) farm management; D) social network; E) perceived challenges and barriers.

2.3.5 Participant observation

Ethnographic data was collected over nine months (Spring 2022 – Winter 2023). Researchers attended three field days, five organizational gatherings, conducted two field-visits and hosted one workshop with students, farmers (conventional, organic, and agroecological), policymakers and other researchers. Out of 14 activities, eight were focused on conventional producers, and six were focused on organic and agroecological producers. Participant observation is a research method where the researcher is immersed in the day-to-day activities of participants, playing a role in a social setting while also taking notes, asking questions, observing, and analyzing (Guest et al., 2013). By taking part in activities and interacting with members of a community in an informal, non-academic way–while being forthcoming about our roles and the nature of our project–participant observation helps researchers to engage more deeply with the lived realities and embodied experiences of participants. Field-visit, field day and organizational gathering observations were recorded immediately after interaction between the research team and potato producers. Interview and workshop notes were recorded in a similar manner.

2.3.6 Farmer field days and field visits

BMP demonstrations were held at farmer field days in Elora, Ontario by the University of Guelph (UofG), and Alliston, Ontario by the Ontario Potato Board (OPB) in 2022 and 2023. UofG hosted roughly 15 people per event, while the OPB field day hosted roughly 75 participants. Researchers participated in informal conservation and engagement with diverse individuals and groups at these events. Demonstrations were oriented around the use and adaptability of new varieties of potatoes, and on the application of machinery in-field to mitigate soil loss. These demonstrations were informed by current research conducted by the University of Guelph potato research lab, and current innovations being practiced by large-scale producers (in the case of the OPB event). Field visits were conducted in Simcoe County during peak potato harvest and included eight fields and one potato storage and processing site. The fields visited were illustrative of four distinct management approaches, and featured seven unique combinations of management approaches and crop variety.

2.3.7 Organizational meetings

Researchers attended four organizational meetings between November 2022 and March 2023. The Ontario Potato Board Annual General Meeting is held every December in Guelph, Ontario. There are roughly 100 people in attendance including board members, conventional medium and large-scale producers, researchers and policy makers from OMAFRA and agri-food Canada, and

1 The Ontario Farm Producers Marketing Act regulates that farms producing over 5 acres of potatoes must be licensed annually with the Ontario Potato Board Membership (2024).

organizations sponsoring the event (agricultural banks, agro-chemical companies, seed distributors, farm machinery manufacturers). The OPB also hosts the Ontario Potato Conference every March with medium and large scale growers from various provinces. This event is attended by roughly 400 guests and features presentations and knowledge sharing, networking, and sponsored booths. In November, the Ecological Farmers' Association of Canada (EFAO) hosts a series of 'Regional Gatherings' for small-scale producers operating in organic and agroecological production systems. This is not specific to potato production and hosts roughly 150 diverse growers from across Ontario. The Ontario Seed Potato Growers Association (OSPGA) hosts their yearly AGM every March in alignment with the OPB AGM because many of its members are also OPB members. The seed sector is much smaller and its membership is limited to 15 producers. Attendees at this event supply seed potatoes to producers across Canada.

2.3.8 Workshop

A workshop was hosted at the University of Guelph in February 2023, featuring presentations and a panel discussion with three of our key informant farmers. Students, OMAFRA staff, farmers, and researchers were in attendance. The event focused on differences and similarities between farmers from three distinct production typologies (large-scale intensive conventional, medium-scale intensive organic, small-scale agroecological), examining possibilities for future collaboration between producers.

2.3.9 Discourse analysis

Discourse Analysis (DA) was applied to analyze study results. DA is used to analyze language use in context, including interview and focus groups transcripts, conversations, published and web-based literature, and videos (Hodge, 2017). Context will affect the general use of language, and its "situated meaning" (how it is being used) (Handford and Gee, 2013). DA looks at the general meaning or communicative purpose of a 'form' (word, phrase, piece of dialog) and the situated meaning (relationship between a forms' literal meaning and the way that it is shaped, distorted, affected by context) (Handford and Gee, 2013). DA helps us to analyze contextual meanings of language by describing realities and evaluating them (Fairclough, 2013). Critical Discourse Analysis (CDA) emphasizes the exploration of social realities and constraints that positively or negatively affect people to understand sources of inequality and how they can be addressed (Fairclough, 2013). Examining the meaning of the world through a particular perspective, CDA helps to understand underlying challenges impacting diverse farmer typologies based on their contextual realities.

3 Results

In total 25 survey responses were collected out of 147 producers registered with the OPB and therefor producing over 5 acres of potatoes. Respondents represent farmers from diverse management approaches and farmer groupings, and collectively representing over 11,600 acres of potato production in Ontario, out of 37,180 acres of potato cultivated land reported by Statistics Canada (2024). Qualitative data (focus groups, workshops, and participant observation) was triangulated with quantitative survey data to reveal complementary and supplementary relationships between both sets of findings. This revealed farm-characteristics of small-, medium-, and large-scale producers, helping us to cluster farmers and their farming operations according to their size. Participants were clustered into three farmer typologies including: Small-scale producer (<150 acres), Medium-scale producer (150–750 acres), and Large-scale producer (>750 acres). These farmer typologies emerged through engagement with producers and other stakeholders from OMAFRA, the OPB, EFAO and OSCIA and created the foundation for our analysis. No formal division of typologies based on size exists for this sector, however, in Ontario, Jansen et al. (2023) report that small-scale farms represent those which are 10 acres or less, medium-scale represents 10–1,119 acres and large-scale represents larger than 1,120 acres. Through conversations and consultations with producers in each category, these categories were updated to represent the potato sector which includes large-scale farmers operating on the majority of potato producing land, medium-scale farmers producing for local, mainstream and organic markets, and small-scale farmers producing for local, urban, niche, and organic markets. Sub-groupings also emerged which reflected the production styles practiced within the farmer-typology grouping, including conventional, organic and agroecological. Organic producers are those who have been organically certified according to the Canadian Organic Standards (COS), which prohibits the use of genetically modified products and materials, nanotechnology, irradiation, cloned livestock, fungicide use, chemical fertilizers, pesticides and herbicides (with few exceptions, listed in CAN/CGSB-32.311), and veterinary drugs (with few exceptions listed in CAN/CGSB-32.310-2020) (Standards Council of Canada, 2021). Agroecology is an approach which focuses on the application of ecological principles to agricultural practice (Altieri, 1996). There is no common definition for agroecology in Canada, but this style of production can be characterized by the integration of crops and livestock in farm management, reliance on organic inputs, and cycling of nutrients on-farm through preparation of compost or green manure (Isaac et al., 2018). There is similarly little consensus over definitions of Conventional production, as this name implies a dichotomous, homogenous category against which all alternative, agroecological and organic approaches are defined against (Sumberg and Giller, 2022). For this study, we define conventional according to the characteristics of the most dominant form of production, as described above, which include large-scale, intensive, and mechanized modes of production. This study identified that all three production styles were present within the small-scale producer typology, but due to their limited representation within this community, for the purposes of our discussion this paper will focus on small-scale organic and agroecological farmers.

3.1 Farm characteristics and demographics

3.1.1 Survey

Respondents' age varied from 35 years (youngest) to 76 (oldest) with an average age of 55.5 years old, and gender skewed male (72%). Reported annual income ranged from $9,000 to $6,000,000, with anywhere from 0 to 90% of that being associated with potato production. The average farm size was 510 acres, ranging from 0.25 to 3,000 acres. All respondents reported owning at least some of their farmed land, and 58% reported renting additional land.

3.1.2 Qualitative findings

In conversation, participants repeatedly noted the lack of young farmers in the sector. This was associated by many with rising land costs and challenges faced by new entrants. In some cases, farm roles and responsibilities were demarcated by age with younger family members tasked with record keeping and data tracking. In other cases, these roles were more closely associated with gender, as many participants reported that their wives typically manage the bookkeeping or reporting. Proximity to markets emerged as a factor impacting income and economic capacity of farms. Smaller farms are more likely to be profitable when located closer to urban or peri-urban centers where their market and consumer base is located. Many producers noted increasing strain from the rising cost of land. Although most farmers we interacted with owned some agricultural land, many reflected that they were facing pressure from other farmers and developers to sell their property. Some participants pointed to rising land cost as a key driver of farmland consolidation, and many believed urban encroachment was also partially to blame.

3.2 Farm management

3.2.1 Survey

To investigate use rates of BMPs, respondents were asked about the on-farm practices they employed, including use of organic or inorganic inputs (fertilizers, pesticide), tillage practices (conventional,[2] reduced,[3] no-till), use of cover crops and use of crop rotations. As reflected in Figure 1, roughly one quarter of respondents reported using solely organic fertilizer (24%), while the remaining respondents used inorganic inputs in some capacity (all inorganic, mostly inorganic, half and half, mostly organic). Similarly in Figure 2, roughly one-quarter (28%) of respondents used solely organic pesticides, while the remaining 72% reported using inorganic in some capacity. The number of respondents using conventional tillage (39%) was similar to those using reduced (35%), while few respondents (9%) reported use of no-till practices. Conversely, cover cropping and crop rotation were almost ubiquitous. Three quarters (74%) of respondents reported using cover crops in some capacity and all respondents (100%) reported using crop rotation in some capacity.

3.2.2 Qualitative findings

In conversation with farmers, several large-scale producers reported that their agrochemical use was reduced from previous years (fertilizers, pesticides) for multiple reasons including the increased price of inputs, government and corporate regulations on pesticide and fertilizer use, and concerns about soil health. That being said, no large-scale producers we met with could be classified as organically certified. Feeling that chemical use was harmful to human health, medium-and small-scale organic producers replaced petroleum based fertilizers with compost, organic fertilizer and cover crops, and replaced chemical pesticides with biofumigants, commercial organic pesticides and integrated pest management[4] (IPM) practices including 1–2 year rotations with cereals, selecting pest resistant varieties, spatial and temporal crop diversification, and regular surveillance and monitoring of pest incidence (VanderZaag, 2010; Barzman et al., 2015). These producers were more likely to report weed control as a challenge as there are few commercial organic herbicides approved for use in Canada. To mitigate weeds on organic farms, intensive tillage practices are common for potato producers. Tillage is associated with increased risk of erosion and poor soil health and requires the use of diesel-powered machinery which many felt contributed to increased greenhouse gas emissions (GHG). Cover crops were widely used to mitigate the impacts of tillage and erosion, and to promote soil health and increased soil organic matter. Cover crops and crop rotation was

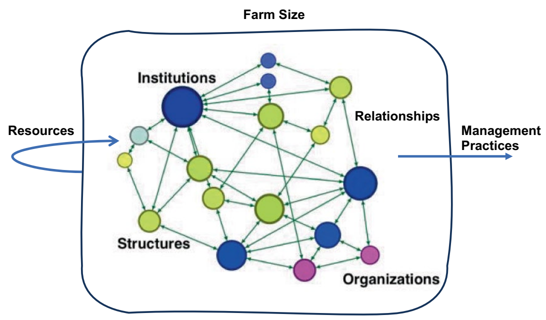

FIGURE 1
Systems framework.

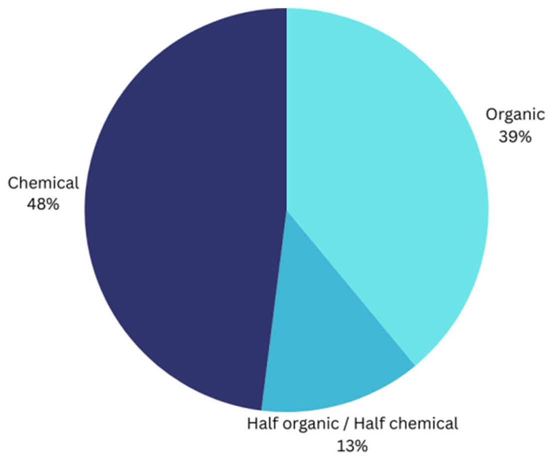

FIGURE 2
Participants amendment management.

2 Conventional Tillage "incorporates or buries most of the crop residue into the soil. Typically this approach involves multiple passes in fields. The moldboard plow is often used first, followed by other implements. Since this method plows under much of the crop stubble, it leaves the surface relatively bare and without cover protection" (Hofmann, 2015).

3 Reduced Tillage refers to a reduction in tillage from what was used in conventional practice (Gouvernement du Canada, 2014).

4 Integrated Pest Management is an approach to pest control that considers and integrates "all available practices and technologies to keep pest populations below economic thresholds while minimizing the impact to the environment" (OMAFRA, 2017, p. 293).

common but used for diverse purposes (promoting pest control and biofumigation, weed control, improved soil filtration). Crop variety and length of rotation was determined by farm size, the identified purpose, and value of the non-potato crop for the farmer's income. While the most diversity was observed amongst the small-scale farmer group, the use of Rye, Clover, Grass/Hay, Oats, and Radish were common across all typologies. As one farmer noted, "We do not have the luxury of more than a 2-year rotation of potato crop. We do not have that much land. So, if there's no potatoes here, I do not have another crop here that I'm trying to profit from" (Potato farmer, Norfolk County). Many farmers told us that crop rotations are not always financially beneficial in the short term due to lost income from land being taken out of production or added cost for seeds or inputs (including irrigation); but they believe that they are a long-term investment in productivity, and that cover crops "pay for themselves in yield resiliency" (OMAFRA soil health specialist) (Figures 3–10).

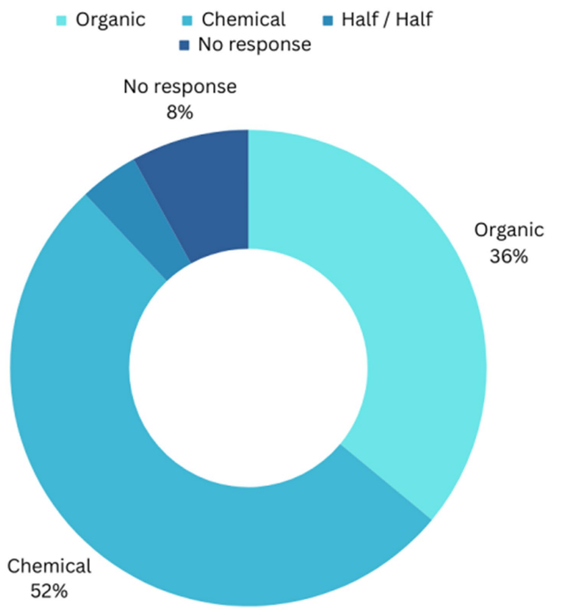

FIGURE 3
Participants pesticide management.

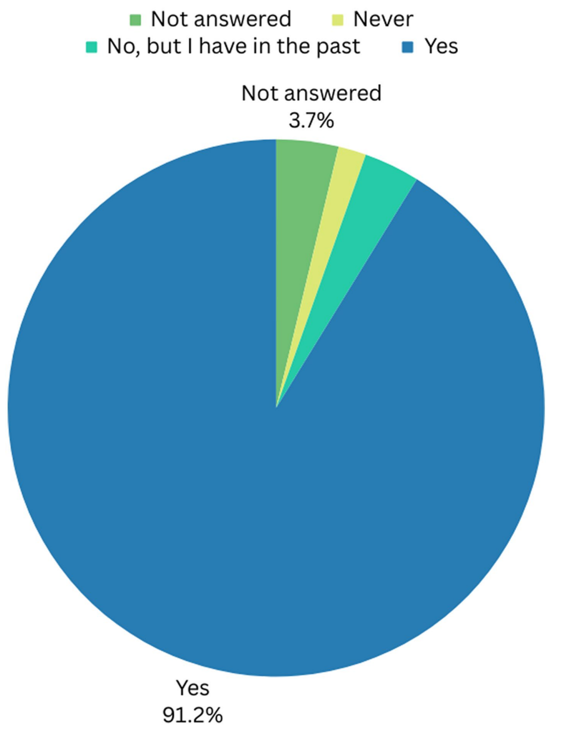

FIGURE 4
Participants cover cropping.

3.3 Social network

3.3.1 Survey

To understand the social networking and knowledge sharing farmers participate in, eight questions were asked about the ways that farmers learn about management approaches, which farmers associations they have membership in, what their engagement with farmers associations and OMAFRA is, and how likely they are to trust information provided to them from the OPB or their peers. Trust is an important aspect of knowledge sharing, so it is important to understand which information sources are most trusted, which varies across farmer typologies. Large-scale farmers reported the most trust out of all three groups for the information provided by the OPB (80%), compared to Medium-scale (71%) and small-scale (62%). While based on survey results, Medium-scale respondents reported the highest trust in information from peers and neighbors (72%), compared to small-scale (61%) and large-scale producers (40%). Small-scale farmers' reported similar membership or affiliation with farmers' associations (52%) as medium-scale farmers (57%), while no large-scale farmers reported any affiliations. Out of all the associations listed, EFAO was most common.

3.3.2 Qualitative findings

The strength and importance of social networks between farmers in this sector was varied and reflected differences in farm size and management approach. While medium-scale farmers reported the highest degrees of trust in information from peers and neighbors (according to survey results), this was not echoed in qualitative observations, suggesting that this form of peer-to-peer learning may be a social expectation, but difficult to follow. For large- and medium-scale farmers, competition for land, market-share and resources emerged as a barrier impacting the likelihood of farmers to trust their peers and neighbors. One farmer advised, "farmers like to rubberneck. You do not ask what the neighbors are doing, you look as you are driving past their farm." Producers feel cautious about sharing information with peers, potentially because of the threats posed by increased economic pressure and fears over consolidation of farms. As another farmer told us, "land prices create silos and competition for land is a real barrier to building bridges." For small-scale producers however, social networks and inclusion and engagement in farmers' associations including EFAO and OSCIA were more common amongst participants.

Regional farmers' associations (including OPB, OSCIA, EFAO, OFA) help to facilitate networking and knowledge exchange between producers but these networks and exchanges differed between farmer typologies and associations. EFAO gatherings were largely attended by small-scale, organic and agroecological farmers including but not limited to potato producers who fell into the 'organic' and 'agroecological' subgroupings. This was reflected in our survey results where most small-scale farmers who reported affiliation with farmers' organizations reported engagement and membership with the EFAO. OPB meetings were predominantly attended only by medium-and large-scale potato producers. Both organizational meetings offered networking and engagement opportunities, but because of the smaller, more informal style of the EFAO gatherings which the research team attended, attendees were encouraged to communicate and exchange knowledge, fostering iterative and active peer-to-peer learning. At the EFAO regional gathering, several participants reported the importance of learning from their peers and neighbors about ways to address common problems. The larger, more formal style of the OPB conference encouraged more unidirectional sharing of knowledge, from presenter to audience, with less chance for audience and peer engagement.

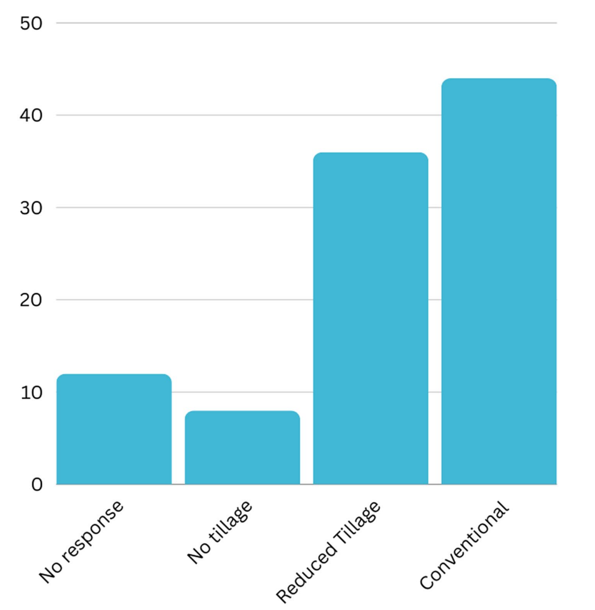

FIGURE 5
Participants tillage managed (by percentage).

3.4 Perceived challenges and barriers

3.4.1 Survey

When asked which factors had the greatest impact on crop yield, respondents ranked their top choices out of list of options (disease, extreme / unpredictable weather, soil quality, water quality, erosion, pests, lack of adequate infrastructure, and lastly, access to capital) with Extreme / Unpredictable weather listed most commonly as the greatest concern (76%) and water quality as the least commonly cited (no respondents). Respondents were then asked to rank and select which issues most concerned them regarding their farming operation out of a list of options (Rising land prices, Maintaining / increasing crop yields, farm-income / market price of potatoes, energy and resource use, crop quality, weather / environmental change, price of external inputs). The most cited first choice was weather and environmental change (56%), followed by farm income and market price of potatoes (48%), with crop yields least commonly cited (24%). For one-quarter of respondents (24%), the choice to adopt certain practices was also influenced by start-up costs associated with BMPs. Similarly, one-quarter (24%) of respondents reported that compliance regulations including CanadaGAP requirements impacted their decision-making.

3.4.2 Qualitative findings

The degree to which certain challenges impacted different groups largely depended on the size, management approach, and location of the farm.

3.4.2.1 Disease

Many participants noted that Late Blight (a communicable disease) is more likely to emerge in organic fields, but that it will often spread to neighboring fields throughout the region. Producers of all

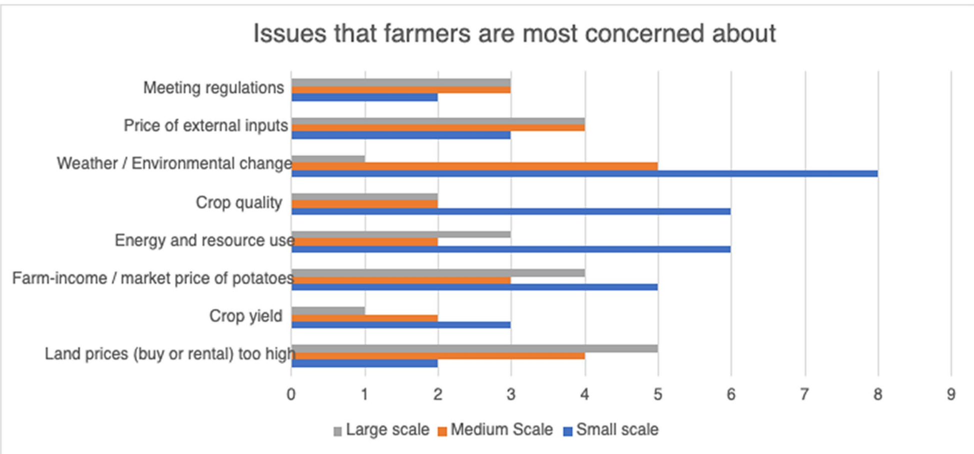

FIGURE 6
Issues that respondents feel most concerned about.

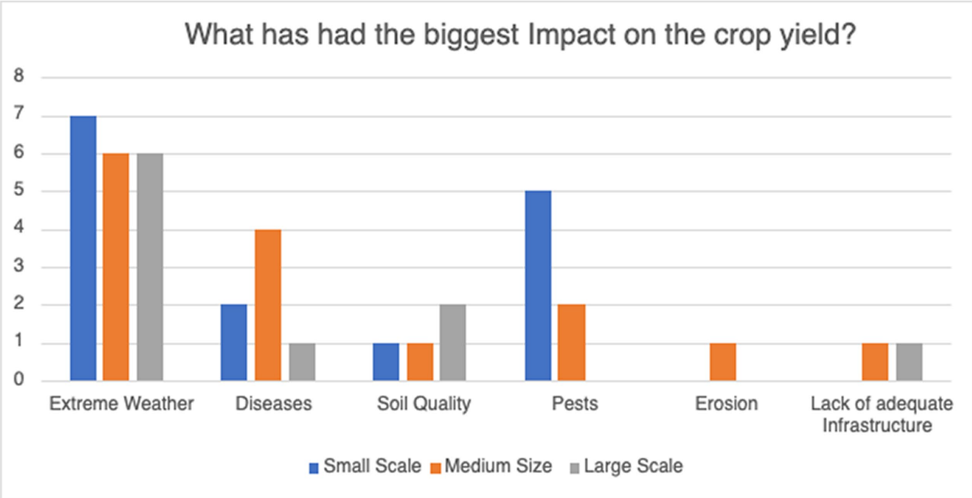

FIGURE 7
Factors most impacting crop yield.

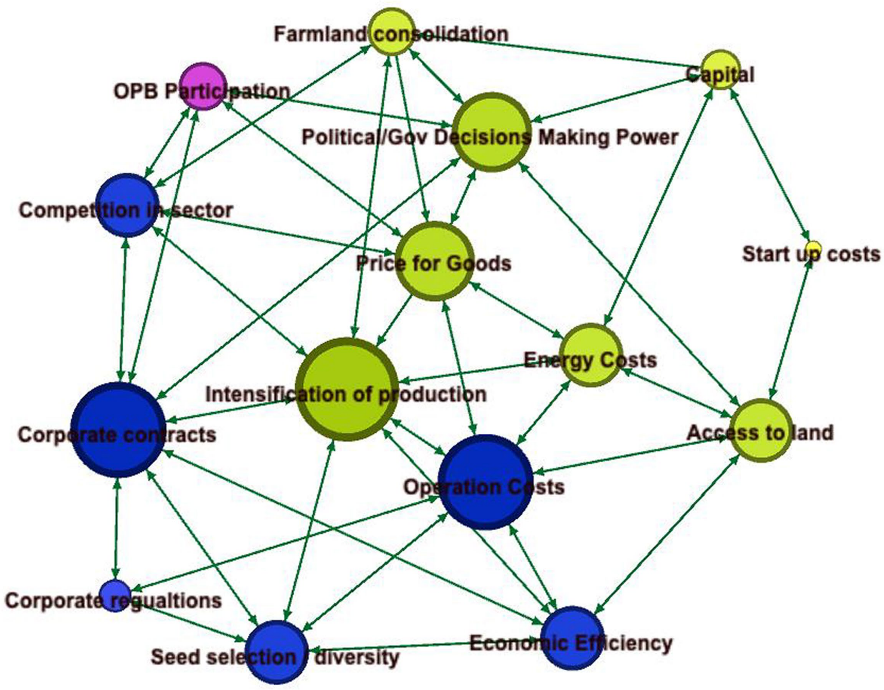

FIGURE 8
Large-scale factor network.

sizes select disease resistant varieties to mitigate disease vulnerability, but smaller farms will also maintain higher rates of diversity[5] (compared to large- and medium-scale farmers) to reduce their vulnerability to outbreaks as genetic variation provides protection against loss (Thrupp, 2000; Hammer et al., 2003). Citing concerns over the increasing prevalence of pesticide-resistant bugs and insects, selection of pest-resistant varieties was an important best management approach for farmers.

Soil health, soil quality and erosion were high priorities across farmer typologies, but variation in soil amendments and stewardship reflected differences in farm size and production styles. Some suggested that wind intensity and lack of rainfall caused by climate

5 Small-scale farmers exhibited higher rates of on-farm crop diversity than their medium- and large-scale counterparts. These findings are based on survey data (use of cover crops, income sources) and qualitative observations from field visits and farmer discussions which revealed that potato production represents a smaller proportion of farm income.

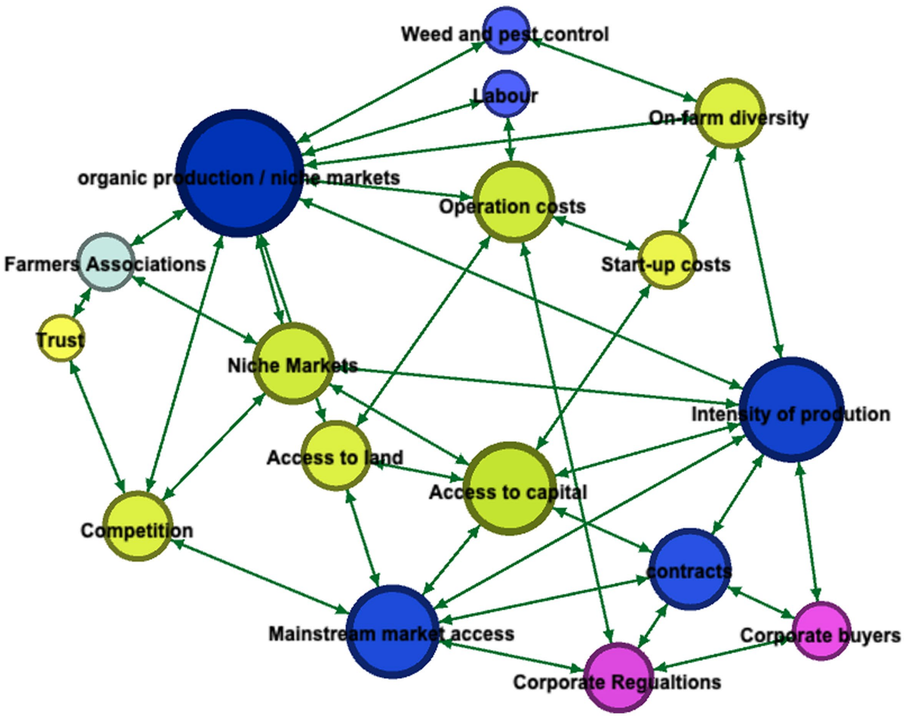

FIGURE 9
Medium-scale factor network.

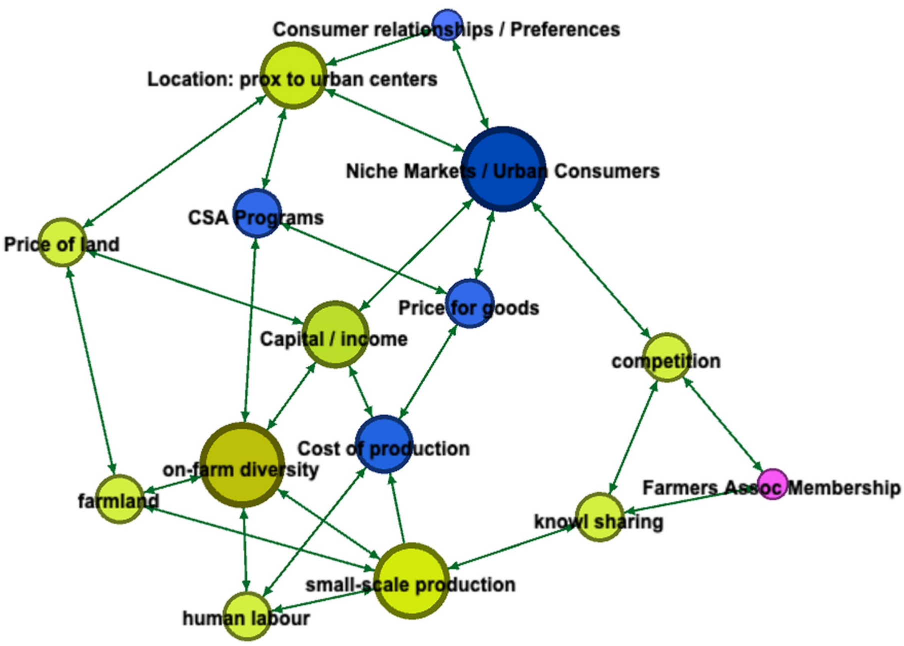

FIGURE 10
Small-scale factor network.

change increased their risk of erosion, with long-term implications for soil health and productivity.

Extreme weather was common amongst survey participants but was not widely discussed throughout field-visits and in-person engagement. Several producers expressed lack of concern for climate change, feeling that it was not happening, or believing it to be positive for potato production in Ontario. As one producer told us, "increased atmospheric CO^2 is actually a positive contribution to increased crop yields which will be important for the future food security of a growing population."

Profitability and farm income were discussed differently by small-, medium-, and large-scale producers, due to differing revenue sources. Medium- to large-scale farm incomes are often tied to fewer, bigger, long-term contracts with processing companies (PepsiCo, Super Pufft, Olde York) ranging from five-to-ten years and limiting farmers' ability to adapt their crop to changing conditions. Small-scale farmers largely sell through Community Supported Agriculture (CSA) programs, farmers markets, and farm stores, meaning proximity to urban centers is important. Several producers who produce potatoes for the 'organic' market discussed the risks and labor requirements associated with organic production. While premiums are paid for organic produce, these are only applied when potatoes are uniform and blemish free (as is also true for non-organic produce), but given the greater cost of organic production, the financial risks for organic producers is greater (Tables 1–5).

3.4.2.2 Rising costs

Several producers felt that rising land and production costs were threatening profitability and driving increased farm-land consolidation as those farms lacking the capital needed to cover the increased cost of production may no longer be able to sustain their operations, becoming financially unviable and leading to the dissolution or sale of their farm. Several producers noted that 2022–2023 has been the most expensive crop planted to date, self-reporting a 20–50% increase in input costs. As fertilizer prices increase, several farmers noted the need for more precise and specific soil amendments.

3.4.2.3 Regulations

Attendees of OSPGA Annual General Meeting called for increased legislation for seed production in Ontario, including respecting new varieties introduced in the province, providing royalties to breeders, and encouraging business related to seed production. Large-scale chip potato producers referenced CanadaGAP requirements as a source of pressure. CanadaGAP. is a third-party food safety certification program for companies that produce, handle and broker fruits and vegetables (CanadaGAP, 2018). Certification is not federally required, but can be requested or included as a stipulation for sale and distribution by companies or customers involved in the brokerage of fresh fruits and vegetables who need to show their customers that food safety programs are being implemented (CanadaGAP, 2020) These include multiple inspections per year and extensive reporting. One farmer informed us that the CanadaGAP COVID-19 response limited external visitors to farms, impacting their ability to sell locally and directly from their farm. Compliance standards imposed by CanadaGAP, PepsiCo, and other buyers require extensive reporting and data entry which can require additional staff. As these formalized compliance standards are set by corporate buyers, small-scale farmers who sell directly to consumers and do not supply to processing companies have more flexibility in their production practices as they do not need to meet certain stringent requirements. Smaller farms are less impacted by these requirements because they often sell through more informal channels where these certification requirements are not called for, including sale through farmers markets, on-farm sales or through CSA programs.

4 Discussion

There is significant diversity of BMPs used throughout the potato sector because of diverse contextual realities, *in-situ* challenges, and specific needs of individual farmers. Problems and goals are set by farm managers according to their understanding and definition of success–as defined by their values–which inform the trade-offs made in their production approaches. A common message echoed by diverse farmers was that 'sustainability' was important, and that farmers in Ontario were already practicing sustainable methods. This message was reiterated by Shawn Brenn, director of the OPB at the Ontario Potato Conference who stated, "Farmers have always used Best Management Practices, but we have not done a good job at telling our stories and showing how innovative we are." That being said, it is important to recognize that BMPs can be 'sustainable' in one area while having adverse effects in another (Bijttebier et al., 2015). Their

TABLE 1 Farmer typology characteristics.

Farmer Typology	Small-scale producers (44% of respondents)	Medium-scale producers (28% of respondents)	Large-scale producers (20% of respondents)
Size	Under 150 acres	150 acres – 750 acres	750 acres or more
Production style	Conventional Organic Agroecological	Conventional Organic	Conventional

TABLE 2 Cover crop usage by farmer typology.

Farmer typology	Cover crops	Applications
Small-scale	Rye, clover, grass/hay, oats, radish, peas, buckwheat, barley	Biofumigation Pest control Weed control Soil erosion Soil organic matter development Prevent nutrient leaching Diversified income
Medium-scale	Rye, clover, grass/hay, oats, peas, buckwheat, hairy vetch	
Large-scale	Rye, clover, grass/hay, oats, radish	

TABLE 3 Trust and organizational participation by farmer typology.

Farmer typology	Trust in peers	Trust in OMAFRA	Trust in OPB	Assoc. participation
Small-scale	61%	37.5%	62%	EFAO OSCIA NFU Regeneration Canada Common ground Canadian chestnut Council OFA
Medium-scale	72%	50%	71%	EFAO OSCIA OPB OSPGA CCF Regeneration Canada COG OCO Farmers for climate solutions
Large-scale	40%	80%	80%	OPB OFA

TABLE 4 Challenges and trade-off by farmer typology.

Farmer typology	Management practice	Motivation	Trade off
Medium-scale	Organic inputs	Human health Soil health	Weeds Increased tillage Erosion
	Cover crops	Integrated pest management Erosion control Soil health/SOM Weed control	Access to land profitability Taking land out of rotation
Large-scale	Reduced agro-chemical Use	Price of inputs Corporate regulations Soil health	Farm size
Small-scale	No-Till	Soil health Integrated pest management Erosion control	Labor intensive Machinery required

use is determined by what needs to be accomplished, what challenge is being addressed, and the goal of the intervention. For example, organic producers who reduce their agro-chemical use by eliminating commercial herbicides face greater tillage requirements, increasing erosion and soil degradation risk (Torresen et al., 2003; Moonen and Barberi, 2004; D'Emden and Llewellyn, 2006; Vasileiadis et al., 2007; Alletto et al., 2011). For these organic producers, reducing chemical input use to reduce chemical runoff and support human and ecosystem health is a priority. Adding to this, certain BMP categories (including cover cropping or crop rotation) will have different outcomes depending on the problem they are being used to address. Discussing the role and importance of cover crops, one producer at the Ontario Potato Conference in 2023 stated, "everyone has a different perspective on cover crops, and it all depends on how you are gonna use 'em." Cover crops may be used for biofumigation and IPM, building soil organic material and improving fertility (Kruger et al., 2013), covering and protecting soils from erosion, reducing compaction and improving soil structure and contributing towards water management (Ontario Ministry of Agriculture, 2018). Different goals influence selected species, seasonality, and timeframe of cover crop use.

4.1 Defining "sustainability"

In addition to BMP use being determined by what needs to be accomplished, their use is also based on the beliefs, values, and motivations of producers (Adger et al., 2009; Bagheri, 2010; Weber and Alberta, 2017). Most producers, regardless of size will likely be motivated by a desire for productivity and profitability, but they will also want to ensure that their practices can be sustained. For producers in Ontario, although 'sustainability' is a commonly discussed concept when discussing the use of BMPs, there are various, conflicting motivations driving the uptake and use of different management

TABLE 5 Structural, institutional and organization drivers and barriers impacting farmer typologies.

	Structural	Institutional	Organizational
Small-scale producer	On-farm diversity Small-scale production Capital/income Location – proximity to urban centers Farmland Competition Knowledge sharing Human labor Price of land	Niche markets/consumers Cost of production CSA programs Price for goods Consumer relationships/preferences	Farmers association participation
Medium-scale producer	Access to capital Operation costs Niche markets On-farm diversity Competition Access to land Start-up costs Trust	Organic production regulations Intensity of production Mainstream market access Corporate contracts Farmers associations participation Weed and pest control Corporate regulations Labor	Corporate buyers Farmers association participation
Large-scale producer	Intensity of production Political power Price for goods Energy costs Access to land Farmland consolidation Capital Start-up costs	Corporate contracts Operation costs Seed selection Economic Efficiency Competition in sector Corporate regulations	OPB participation

approaches, and often, multiple motivations exist at one time. Sustainability and productivity can vary based on the timeframe over which these farms are productive (for how long), the scale on which they can produce (what is the level of production trying to sustain), and the scope of those impacted (who will benefit from the sustained production). In this context, 'Sustainability' is defined by the ability of a productive system (farm) to continue to be productive and to continue to operate as a farm for future generations, but the means through which long-term productive capacity is achieved will differ. As reflected in the literature, definitions of sustainability are diverse and represent an amalgamation of motivational drivers that define a producers' vision of time, scope and scale (Liu et al., 2018). A novel finding not reflected widely in the literature on motivational drivers for BMP use however was that these definitions of sustainability are not necessarily connected or related to environmental stewardship. Often, the primary value of a BMP is determined both by its immediate and its long-term productivity and profit, and farmers make decisions about which aspects of their farm should be prioritized to ensure short-term productivity and long-term sustainability. The trade-offs producers make to ensure short-term and long-term productivity reflect their underlying beliefs about the meaning of sustainability, and how they value different aspects of their farm operation. Therefore, sustainability is a complex and multidimensional concept that can mean many things to many people, and for it to be useful in understanding motivations, it should be understood contextually and holistically.

While it is widely agreed that promoting the health and stewardship of the natural environment is required for long-term productivity and sustainability [Tilman et al., 2002; NRC (National Research Council), 2003; Robertson and Swinton, 2005], socio-economic position and farm characteristics (size, crop portfolio, consumer base/market) impact trade-offs producers make to ensure their continued productive capacity and the strategies they have available to them. The agency of producers' to act according to their values, beliefs and motivations is limited by structural, institutional and organizational barriers shaping their contextual realities (vulnerabilities, opportunities), depending on their size, market, management approach, access to capital, and relationships (Urwin and Jordan, 2008; Hernández-Jover et al., 2012). Farmers BMP use can therefore be understood in terms of their underlying beliefs about long-term productivity and sustainability, combined with their institutional and structural context.

4.2 Motivating drivers

Based on our research and analysis, several overarching, overlapping, and sometimes conflicting motivations have emerged which combine to form producers' conceptions of sustainability. These motivations represent diverse dimensions of sustainability including social, environmental, economic, health, and political factors (Banson et al., 2015). Understood within a systems thinking approach, these motivating drivers represent the different mental models experienced by participants within the sector and. Mental models are deep-rooted generalizations that influence the ways that we understand the world and take action within it (Senge, 1997). They are reflected in our conceptions of sustainability and they provide a framework for understanding the aspects that need to be considered when conceptualizing and developing approaches to sustainability.

4.2.1 Efficiency and profitability

Efficiency and profitability were cross-cutting motivating drivers for most producers because farming is a business and businesses need to be profitable (Glover and Kusterer, 2016; FAO, 2020). Profitability is an important aspect of sustainability because farms must be financially viable to continue to produce. However, profitability can be measured in both short and/or long-term gain (Ikerd, 1990). When farmers act in terms of long-term profitability, multiple other decision-making factors must be considered. Discussing the financial benefits of cover crops, one participant noted that cover crops pay for themselves in yield resiliency. For this farmer, the upfront cost was worth it to ensure long-term sustainability and profitability. Another participant explained that in rotations with only field crops[6] cover crops do not pay, but in vegetable rotation they do. The use of BMPs may involve financial risk, including high start-up costs, or the requirement to take a proportion of land out of production. For producers with tighter margins, the short-term cost for a long-term investment might not be feasible.

4.2.2 Family and future generations

Family emerged as a strong motivating driver for farmers throughout the sector, but especially for medium-scale and large-scale producers. Because potato production in Ontario largely takes place on family-owned farms (with a few exceptions), you can see multiple generations working together. Many participants described working on the same land that their grandparents or great grandparents farmed on. In many cases, families immigrated from Europe (The Netherlands, Poland) and settled in Ontario. For these producers, their farms are deeply associated with their familial history, imbuing it with both economic and sentimental value. Connection to family through past and future generations drives the desire to maintain their farms, and to farm in a way that ensures its continued use. Soil health and productivity was discussed in reference to land's carrying capacity–not only for their use, but also for their children and grandchildren. However, as farmland costs increase alongside urban encroachment, and the rising costs of production, farmers are faced with the choice of selling their land or maintaining a potentially economically unsustainable operation. One participant told us, "Farming is a passion. Some farmers do not want to give up their land for money. They want to keep farming for future generations." However, there is no guarantee that the children of landowning farmers will decide to stay in the industry. Without children or family to inherit the farm, the choice to sell might be more appealing. For farmers with strong emotional and familial ties to the land they farm on, who have succession plans that pass their land tenure down to their children, sustainability is closely tied to family and future generations.

6 Field crops include corn, cotton, rice, sorghum, soybeans, winter wheat, durum wheat, and spring wheat (USDA Climate Hub, n.d.).

4.2.3 Ecosystem and soil health

Farmers consider themselves to be stewards of their land, weighing the ecological damage of management approaches against other factors (e.g., cost, profitability, social implications). For many, ecosystem health is an important aspect of sustainability, but it is often the means to achieve other goals, including productivity (short or long-term). One producer explained, sustainability represents the ability of soil to continue to produce crops year-over-year which depends on the health of the ecosystem. Ecosystem health was often referenced in relation to soil health, measuring ecological decline or climate change in terms of the increasing threat of soil erosion or soil degradation. For many, soil health enables continuous production, and long-term soil quality may have short-term costs but long-term gains. Discussing cover crop use, one producer told us, "You're always asking your soil to give, give, give. So, what if we give the soil a chance to have a rest and we give to it" (Potato farmer, Norfolk County). Many recognize the environmental impact of farming and aim to mitigate its negative externalities. However, they must balance economic realities with their personal values. One organic producer we spoke with described the trade-offs they make when balancing ecosystem health, asking "what are my values as a person? How am I going to make this work financially? Organic might not be the best fit, but it allows me to be a farmer while also caring for the environment in a fitting way." Weighing risks and the rewards of different management approaches comes with a value assessment of ecological versus economic advantages.

4.2.4 Human health

Human health was a consideration for farmers using reduced or organic inputs who believe that reduced chemical exposure is important for the local community and the production system as a whole. When limiting chemical inputs, farmers must restore or amend nutrients in other ways and find alternative methods for pest and weed control (many of which come with their own trade-offs). As described above, reduced chemical herbicide use often involves increased tillage to control weeds (Colbach and Cordeau, 2022), forcing farmers to make decisions about which externalities they are comfortable with. Discussions of personal health are also tied to decisions about labor practices. As one organic producer told us, given the labor-intensive nature of organic production, it's important to keep personal health and wellbeing in-mind to maintain the sustainability of production. For some, sustainability is a delicate balance between personal health, community health, and ecosystem health.

4.2.5 Community and social relationships

Some producers reported acting in the interest of their community. For many, "community" referred to the farming community within their region or within Ontario. For others, community was used more abstractly to describe the general population including consumers. Across farmer typologies, thinking and acting in terms of community was an important aspect of farming and several noted that farmers are likely to collaborate and support each other. "Farmers have to be a community, especially in rural and remote areas" one participant told us, noting that collaboration and community precedes competition. For large- and medium-scale farmers however, community was in conflict with challenges of competition. Related to this, several producers reported that building trusting relationships with other producers was difficult because of competition within the sector. One large-scale producer explained, "it's hard to build bridges when we are all in competition. It's easier once you are established, but harder when you are starting out." Selling to the same markets, relying on a limited selection of buyers, large- and medium-scale farmers are less likely to share knowledge or best practices as compared to small-scale farmers. Amongst small-scale farmers, community and engagement with other farmers was strong. Participation in local farmers' associations was important for sharing practical knowledge and addressing challenges collectively. With diversified consumers and market channels (selling direct to consumer through CSA programs, farmers markets, on-farm sales) small-scale farmers do not feel the same degree of direct competition between each other. This is important as small-scale producers do not have access to the same financial resources or capital of larger producers and so community support and collaboration is critical to address problems and remain viable.

4.3 A systems thinking analysis of BMP adoption – drivers and barriers

Systems are complex and interrelated, and alterations or interventions in one area may have adverse or positive effects in another part of the system (Banson et al., 2015). Mental models can help us to better understand the different yet relational elements of sustainability that should be considered when addressing challenges within a system (Hoffman et al., 2014). This can help to illustrate the implications for sustainability when one aspect of a system is prioritized over another. In the following section, we will examine the implications for these diverse aspects of sustainability. Identifying structural, institutional and organizational factors influencing small, medium and large-scale producers, we use a systems thinking approach, to explore relationships between actors in the system, analyzing how different factors influence different groups of producers to positively or negatively impact the use and uptake of BMPs. By visually mapping these relationships, we identify levels of influence between factors, identifying elements which are highly influential, as well as highly influenced.

4.3.1 Structural, institutional and organizational drivers and barriers

Farmers operate within complex structures, institutions and organizations which may limit or increase their ability to act on their mental models of sustainability. A structure is a set of variables that are relatively stable over time, which affect the behavior of actors within it (Policonomics, 2012; Bosch et al., 2014). An institution is a "system of established and prevalent rules that structure social interactions" (Hodgson, 2006). These include laws, regulations, social norms, governing frameworks, and organizations (Hodgson, 2006). Whether a structure or institution acts as a driver or a barrier will be determined by a producers' size, production approach, and market access; characteristics which are further determined by their access to financial resources, geographical location, beliefs and values, and social or organizational relationships. These factors influence the trade-offs and cost–benefit analyzes producers make when implementing management decisions. When considered alongside other factors including farm-typology (large-scale, medium-scale, small-scale) and motivational drivers, the impact of these barriers on the overall sustainability of the system can be unpredictable. Given the complex nature of these barriers, this study applies a systems thinking perspective to describe the feedback loops that characterize the relationships between each farmer typology, and to identify the differing structural, institutional and organizational influences they are impacted by which create barriers for their uptake of BMPs.

4.3.1.1 Structural, institutional and organizational drivers and barriers impacting large-scale producers

To map connections in the large-scale farmer sub-system, factors were first identified and then grouped based by 'structural', 'institutional', or 'organizational' factor. Based on conservations with farmers throughout the study, links were drawn to connect these elements according to how they act on each other to influence BMP uptake. Using systems mapping software 'Gephi' to visualize these relationships, factors with the greatest number of connections are represented by the largest nodes. Within the large-scale farmer subsystem, the factors that were most highly influenced – meaning that they have the most number of links directed towards them – are corporate contracts, operations costs, and intensification of production. These are also the most highly influential, meaning that they had the greatest number of links emerging from them towards other factors.

Large-scale farmers are the most powerful producers in the sector. They hold the most land, the largest percentage of production, the greatest access to capital, and often have access to political and governmental decision making (Chen and Clark, 2023). Greater access to land may in some cases offer larger farmers greater flexibility to trial new or alternative management practices as they can take on more risk than farmers with fewer resources. Although large-scale farmers hold more power in comparison to other farmers, they still face structural, institutional and organizational limitations that impact their flexibility and agency. These limitations are driven by dependence and power imbalances between producers and corporate buyers resulting from economic and productivity demands which make producers vulnerable to production requirements and regulations that may not benefit them (Friedland et al., 1981; Woodall and Lynn, 2011; Rotz and Fraser, 2015).

4.3.1.1.1 Power of corporations

Compared with small-scale farms, diversification on large- and medium-scale farms is limited (buyers, crops). Many have a few large, long-term contracts with agri-food corporations and large retailers (Walmart, Loblaws, PepsiCo, Super pufft) producing potatoes for chipping, frozen or processed consumption (including soups and stews), wholesale fresh consumption through retailers, and seed. Contracts are often long-term (five-to-ten years). While this provides some degree of financial stability, it can also limit farmers' ability to adjust their crop variety to respond to market volatility, disease or pest outbreaks, or extreme weather. In addition, across many cases, large-scale operations have greater earning potential as well as higher operating costs. These costs include (but are not limited to): price to purchase land, equipment and machinery costs (planting, harvesting, storage), inputs (fuel, pesticides, herbicides, fungicides), salaries, and infrastructure (including quonset huts for storage, farm road maintenance). To be sustainable, farms must cover their costs, so as farm sizes and costs increase, the need for efficiency also increases. Limited diversity combined with increasing demands for efficiency may increase producers' dependence on each buyer, further increasing the bargaining power and market influence of corporations. Competition, combined with the power and influence of agri-food companies result in contracts which work in favor of the corporate buyer which can negatively impact producers. Corporate regulations impact the production approaches of farmers, including the use and selection of inputs (quantity, variety), variety of seed being planted, and uniformity and size of tubers produced. Safety standards, sustainability initiatives, and industrial requirements impose regulations that limit the flexibility and agency of producers to change, adapt and select their management approaches. For example, industrialized chip processing requires uniform potatoes (size, quality, appearance, sugar levels) to accommodate standardized, mechanized production (Work et al., 1981). For large-scale farmers, transitions to alternative practices are difficult and take time. While large-scale farmers have more power within the sector, they are also the least flexible to make change.

4.3.1.1.2 Farmland consolidation

Increased efficiencies driven by competition for contracts and market access benefit some producers while negatively impacting others. While the price for potatoes fluctuates, competition for market access at a global level is translated into competition amongst producers to offer low cost products to buyers and consumers (Qualman and Tait, 2004). Producers are impacted by the increasing cost of energy and production associated with rising fuel, fertilizer and other input costs (Fluck, 2012; Government of Canada, 2022, 2023), and those who cannot outcompete while covering their growing costs will be edged out of the sector (Sparling and Thomspon, 2011). As rising production costs drive small-and medium-scale producers out of the sector, there is increasing consolidation of farmland by large-scale operators (Blais et al., 2021). With fewer farms, there is greater pressure on the remaining producers to fill the gaps in the market, reinforcing the need for efficiency within the sector, and further incentivizing the consolidation and growth of farmland. While this benefits larger farmers, it may also negatively impact the sector as farm diversity is lost.

4.3.2 Structural, institutional and organizational drivers and barriers impacting medium-scale producers.

Within the medium-scale farmer subsystem, there were three institutional factors that were most highly influential on other factors. These were organic production (regulations, requirements), the intensity of their production, and their participation or access to mainstream markets. This is because market participation, whether mainstream or organic, is mediated by sets of rules, requirements from buyers, contracts, consumer preferences, and regulatory bodies. These institutional frameworks influence farmers access to capital, and the trade-offs in decision making they will make.

Medium-scale producers are diverse, including producers who supply to conventional and organic markets with varying financial resources, land, and market channels. Because they operate on less land than large farmers, medium-and small-scale producers can take advantage of a different set of opportunities, including producing potatoes for the organic market. Organic production is more labor intensive as certain processes associated with the management of weeds and pests cannot be mechanized (Sørensen et al., 2005), which makes these production systems more difficult to manage as farm sizes increase. Organic medium-scale farmers are subject to corporate regulations, including organic certification requirements which are costly and time consuming, however, they have access to higher value, niche markets which offer price premiums to offset the added costs associated with organic production and separates producers from mainstream markets where it is more difficult to outcompete larger farms (Loureiro and Hine, 2002).

4.3.2.1 Market participation

Conventional medium-scale producers occupy a difficult space. Because small-scale farms with less acreage, they can apply more labor-intensive practices including production of a more diversified range of products which gives them access to high-value, local and niche markets and grow a more diversified range of products. The more land is managed, the more labor intensive and inefficient this becomes. Therefore, many conventional medium-scale producers compete in the same markets as large-scale operations but have fewer resources to mitigate risk. Additionally, corporate regulations impacting large-scale farmers also impact medium-scale conventional farmers. These include significant time and human resources for tracking and reporting data required to meet standards which can add strain to an existing challenge. Financial strain and competition create distrust within the sector, making them less likely to attend producer meetings or seek peer support or advice. This results in fewer opportunities to learn from and share best practices amongst peers to solve challenges. Participation in local and regional farmers' associations can also be an important tool for collective action, increasing the power of smaller producers to lobby for their best interests. Increased distrust amongst farmers, combined with rapid consolidation of farmland reinforces a feedback loop within the sector of further consolidation, further limiting the uptake of BMPs as local innovations are not shared amongst producers.

4.3.3 Structural, institutional and organizational drivers and barriers impacting small-scale producers

Within the small-scale farmer subsystem, we identified structural and institutional factors as influential on decision making and BMP uptake. Niche market access was considered an institutional factor, as it is associated with a set of formal and informal rules and norms including consumer preferences which define goods and actors. Typically, on-farm diversity and income diversity is positively associated with niche market access as participation in niche-markets enables the sale of higher-value crops, which supports diverse production.

Small-scale farmers typically operate with fewer financial resources than large farms (Hoppe, 2010; Ebel, 2020), but more diversity was observed in styles of production (conventional, organic, agro-ecological). Limited productive capacity associated with less physical space impacts the markets and buyers that small-scale farmers will supply to. Supplying to agri-food processing companies such as PepsiCo and Super pufft, and retailers including Walmart and Loblaws is often not financially viable as regulatory requirements and contract stipulations demand economies of scale supported by expensive technology, machinery and infrastructure (Ebel, 2020). Chip production for example requires highly technical storage, testing, and quality assurance processes which many medium-and small-scale producers cannot afford.

4.3.3.1 High value goods

Limited productive capacity (in terms of yield) and a greater reliance on human labor increases production costs for smaller farms. Because of these limitations and the higher cost of goods, small-scale producers typically rely on the sale of goods locally through CSA programs, farmers markets and through on-farm sales. Diversified channels allow smaller farms to access niche markets and different consumers than conventional producers. Proximity to urban centers is key to selling directly to consumers and the success of producers (Blais et al., 2021). Given the higher value and cost of their produce, having access to diverse consumers who can afford to spend more for their goods is important. While limited financial resources increase the vulnerability of small-scale farmers to shocks and stressors, diverse and niche market access through direct-to-consumer sales make these producers more flexible to change as they are less reliant on stipulations and regulations set by corporate buyers. This may create opportunities for the uptake of BMPs amongst this farmer-typology.

5 Conclusion

Best Management Practices are diverse, contextual, and there is no one-size-fits-all BMP that can be applied by every producer (Prokopy et al., 2008). Intimate understanding and knowledge of their farm's context will inform the strategies applied by farmers, but these will also be determined by the needs and the challenges they are trying to address, the resources available to them, and their definition of "success" or the goal they are trying to achieve. The potato sector in Ontario is under increasing climatic and economic stress, increased BMP adoption may help to support sustainability and productivity (McLaughlin and Mineau, 1995; Ontario Ministry of Agriculture, 2018). More specifically, BMPs promoting ecological, soil, and watershed stewardship are recognized for promoting longer-term sustainability (Lehman et al., 2015; Ministry of Forests, Lands, Natural Resource Operations and Rural Development, 2021) making it important to understand which decision-making factors impact BMP adoption.

This study examined the characteristics of individuals and groups throughout the OPS, identifying relationships within and between farmer typologies, organizations, corporations and government institutions to understand how diverse and heterogeneous factors impact the uptake and implementation of BMP use for sustainable potato production. Applying a systems thinking perspective, four feedback loops were identified which illustrate how power dynamics between actors influence farmer behavior and undermine their autonomy and capacity to act according to their values or beliefs about sustainability. Producer behavior is impacted by structural, institutional and organizational barriers which influence the management approaches that are available to farmers and the flows of power between actors in the system. By understanding these motivating drivers and structural and institutional barriers for BMP use, policies and programming promoting the use of sustainable agricultural alternatives should consider how existing structures and sectoral mechanisms influence and promote one-dimensional thinking (i.e., only considering the economic benefits) and address with more focused policies, incentives and improved knowledge sharing.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by University of Guelph Research Ethics Board. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

SS-E: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing. PV: Resources, Supervision, Validation, Writing – review & editing. CP: Formal analysis, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. RZ: Conceptualization, Funding acquisition, Visualization, Writing – review & editing. DS: Data curation, Formal analysis, Visualization, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This work was supported by the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) (grant number UG-T1-2021-101023).

Acknowledgments

We are grateful to all of our project advisors and partners who have helped with the planning and implementation of research activities. This includes OMAFRA, the Ontario Potato Board, the Ecological Farmers Association of Ontario, and the Ontario Soil and Crop Improvement Association. We would also like to acknowledge and thank the potato producers of Ontario who have shared their time, knowledge, and expertise.

Conflict of interest

PV was employed by SunRISE Potato.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Adger, W. N., Dessai, S., Goulden, M., Hulme, M., Lorenzoni, I., Nelson, D. R., et al. (2009). Are there social limits to adaptation to climate change? *Clim. Chang.* 93, 335–354. doi: 10.1007/s10584-008-9520-z

Adopted IPCC (2014). *Climate change 2014 synthesis report*. IPCC: Geneva, 1059–1072.

Agri-Food Canada (2021). *Potato Market Information Review 2020–2021* Agri-Food Canada. Ottawa, ON

Ahmad, U., and Sharma, L. (2023). A review of best management practices for potato crop using precision agricultural technologies. *Smart Agricultural Technology*, 100220.

Allan, C., Cooke, P., Higgins, V., Leith, P., Bryant, M., and Cockfield, G. (2022). Adoption; a relevant concept for agricultural land management in the 21 century? *Outlook Agri.* 51, 375–383. doi: 10.1177/00307270221126540

Alletto, L., Coquet, Y., Benoit, P., Heddadj, D., and Barriuso, E. (2011). Tillage management effects on pesticide fate in soils. *Sustain. Agric. Res.* 2, 787–831. doi: 10.1007/978-94-007-0394-0_35

Altieri, M. A. (1996). *Agroecology: The science of sustainable agriculture*. Agroforestry Systems.

Altieri, M. A., Nicholls, C. I., Henao, A., and Lana, M. A. (2015). Agroecology and the design of climate change-resilient farming systems. *Agron. Sustain. Dev.* 35, 869–890. doi: 10.1007/s13593-015-0285-2

Aydinalp, C., and Cresser, M. S. (2008). The effects of global climate change on agriculture. *Am. Eurasian J. Agric. Environ. Sci.* 3, 672–676.

Babajani, A., Muehlberger, S., Feuerbacher, A., and Wieck, C. (2023). Drivers and challenges of large-scale conversion policies to organic and agro-chemical free agriculture in South Asia. *Int. J. Agric. Sustain.* 21:2262372. doi: 10.1080/14735903.2023.2262372

Bagheri, A. (2010). Potato farmers' perceptions of sustainable agriculture: the case of Ardabil province of Iran. *Procedia Soc. Behav. Sci.* 5, 1977–1981. doi: 10.1016/j.sbspro.2010.07.399

Banson, K. E., Nguyen, N. C., Bosch, O. J., and Nguyen, T. V. (2015). A systems thinking approach to address the complexity of agribusiness for sustainable development in Africa: a case study in Ghana. *Syst. Res. Behav. Sci.* 32, 672–688. doi: 10.1002/sres.2270

Bartkowski, B., Bartke, S., Helming, K., Paul, C., Techen, A. K., and Hansjürgens, B. (2020). Potential of the economic valuation of soil-based ecosystem services to inform sustainable soil management and policy. *PeerJ* 8:e8749. doi: 10.7717/peerj.8749

Barzman, M., Bàrberi, P., Birch, A. N. E., Boonekamp, P., Dachbrodt-Saaydeh, S., Graf, B., et al. (2015). Eight principles of integrated pest management. *Agron. Sustain. Dev.* 35, 1199–1215. doi: 10.1007/s13593-015-0327-9

Bijttebier, J., Ruysschaert, G., Hijbeek, R., Rijk, B., Werner, M., Raschke, I., et al. (2015). *Farmers review of best management practices: Drivers and barriers as seen by adopters and non-adopters*. Wageningen University.

Blais, J. S., Bueckert, C., De Luna, P., and Roberts, M. (2021). *Growing the next crop of Canadian farmers* Ottawa: Public Policy Forum.

Bommarco, R., Vico, G., and Hallin, S. (2018). Exploiting ecosystem services in agriculture for increased food security. *Global food security*, 17, 57–63.

Bosch, O., Nguyen, N. C., Ha, T. M., and Banson, K. E. (2014). *Using a systemic approach to improve the quality of life for women in small-scale agriculture: Empirical evidence from Southeast Asia and sub-Saharan Africa*. Advances in Business Management. Towards Systemic Approach, Perugia, Italy.

Bradshaw, B. (2004). Plus c'est la même chose? Questioning crop diversification as a response to agricultural deregulation in Saskatchewan, Canada. *J. Rural. Stud.* 20, 35–48. doi: 10.1016/S0743-0167(03)00033-0

Bryant, C. R., Smit, B., Brklacich, M., Johnston, T. R., Smithers, J., Chiotti, Q., et al. (2000). Adaptation in Canadian agriculture to climatic variability and change. *Clim. Chang.* 45, 181–201. doi: 10.1023/A:1005653320241

Brzezina, N., Kopainsky, B., and Mathijs, E. (2016). Can organic farming reduce vulnerabilities and enhance the resilience of the European food system? A critical assessment using system dynamics structural thinking tools. *Sustain. For.* 8:971. doi: 10.3390/su8100971

Campbell, I. D., Durant, D. G., Hunter, K. L., and Hyatt, K. D. (2014). "Food production" in *Canada in a changing climate: Sector perspectives on impacts and adaptation*. eds. F. J. Warren and D. S. Lemmen (Ottawa, ON: Government of Canada)

CanadaGAP (2018). Overview of CanadaGAP. Available ay: https://www.canadagap.ca/program/

CanadaGAP (2020). Who needs to be canadagap®-certified?. Available at: https://www.canadagap.ca/faq-items/who-needs-to-be-canadagap-certified/

Chen, Z. J., and Clark, J. (2023). Information on farm operating revenues and expenses help paint a portrait of Canada's agricultural businesses. This article sheds light on farm profitability (by revenues class, operating arrangement, total farm area and farm type) and some potential driving forces behind the profitability trends observed. Canada's farms were more profitable in 2020 than in 2015. Available at: https://www150.statcan.gc.ca/n1/pub/96-325-x/2021001/article/00015-eng.htm

Cloke, P. J., Marsden, T., Mooney, P. H., and Marsden, T. (2001). "The road towards sustainable rural development: issues of theory, policy and practice in a European context" in *Handbook of rural studies* (Newcastle upon Tyne: Sage), 201–211.

Colbach, N., and Cordeau, S. (2022). Are no-till herbicide-free systems possible? A simulation study. *Front. Agron.* 4:823069. doi: 10.3389/fagro.2022.823069

D'Emden, F. H., and Llewellyn, R. S. (2006). No-tillage adoption decisions in southern Australian cropping and the role of weed management. *Aust. J. Exp. Agric.* 46, 563–569. doi: 10.1071/EA05025

D'Emden, F. H., Llewellyn, R. S., and Burton, M. P. (2006). Adoption of conservation tillage in Australian cropping regions: an application of duration analysis. *Technol. Forecast. Soc. Chang.* 73, 630–647. doi: 10.1016/j.techfore.2005.07.003

De Vries, F. P., Van Keulen, H., and Rabbinge, R. (1995). Natural resources and limits of food production in 2040. In Eco-regional approaches for sustainable land use and food production: Proceedings of a symposium on eco-regional approaches in agricultural research, 12–16 December 1994, ISNAR, The Hague (pp. 65-87). Springer Netherlands.

Denscombe, M. (1997) *The good research guide*. Buckingham, Open University Press.

Dessart, F. J., Barreiro-Hurlé, J., and Van Bavel, R. (2019). Behavioral factors affecting the adoption of sustainable farming practices: a policy-oriented review. *Eur. Rev. Agric. Econ.* 46, 417–471. doi: 10.1093/erae/jbz019

Djaman, K., Koudahe, K., Koubodana, H. D., Saibou, A., and Essah, S. (2022). Tillage practices in potato (Solanum tuberosum L.) production: a review. American Journal of Potato Research, 99, 1–12.

Dogliotti, S., Van Ittersum, M. K., and Rossing, W. A. H. (2006). Influence of farm resource endowment on possibilities for sustainable development: a case study for vegetable farms in South Uruguay. *J. Environ. Manag.* 78, 305–315. doi: 10.1016/j.jenvman.2005.04.025

D'souza, G., Cyphers, D., and Phipps, T. (1993). Factors affecting the adoption of sustainable agricultural practices. *Agric. Econ. Res. Rev.* 22, 159–165. doi: 10.1017/S1068280500004743

Dumanski, J., Terry, E., Byerlee, D., and Pieri, C. (1998). *Performance indicators for sustainable agriculture*. The World Bank, Washington, 115–1124.

Eakin, H. C., Lemos, M. C., and Nelson, D. R. (2014). Differentiating capacities as a means to sustainable climate change adaptation. *Glob. Environ. Chang.* 27, 1–8. doi: 10.1016/j.gloenvcha.2014.04.013

Ebel, R. (2020). *Are small farms sustainable by nature?—Review of an ongoing misunderstanding in agroecology*. Challenges in Sustainability, 8, 17–29.

Eisenhauer, T., and Mitchell, M. (2011). *Factors that drive Canadian farmland values*, Bonnefield Research, Toronto, Canada.

Fairclough, N. (2013). Critical discourse analysis and critical policy studies. *Crit. Policy Stud.* 7, 177–197. doi: 10.1080/19460171.2013.798239

FAO. (2015). Agroecology for food security and nutrition. Proceedings of the FAO international symposium; 18–19 September 2014, Rome.

FAO. (2020). *Emissions due to agriculture. Global, regional and country trends 2000–2018. FAOSTAT Analytical Brief Series No 18 Rome*. FAO, Rome

Feola, G., Lerner, A. M., Jain, M., Montefrio, M. J. F., and Nicholas, K. A. (2015). Researching farmer behavior in climate change adaptation and sustainable agriculture: lessons learned from five case studies. *J. Rural. Stud.* 39, 74–84. doi: 10.1016/j.jrurstud.2015.03.009

Fielke, S. J., Botha, N., Reid, J., Gray, D., Blackett, P., Park, N., et al. (2018). Lessons for co-innovation in agricultural innovation systems: a multiple case study analysis and a conceptual model. *J. Agric. Educ. Ext.* 24, 9–27. doi: 10.1080/1389224X.2017.1394885

Fluck, R. C. (Ed.). (2012). *Energy in farm production*. Elsevier.

Fragoso, C., Brown, G. G., Patrón, J. C., Blanchart, E., Lavelle, P., Pashanasi, B., et al. (1997). Agricultural intensification, soil biodiversity and agroecosystem function in the tropics: the role of earthworms. *Appl. Soil Ecol.* 6, 17–35. doi: 10.1016/S0929-1393(96)00154-01

Friedland, W. H., Barton, A. E., and Thomas, R. J. (1981) *Manufacturing green gold: Capital, labor, and technology in the lettuce industry*. Cambridge University Press, Cambridge

Fulponi, L. (2006). Private voluntary standards in the food system: the perspective of major food retailers in OECD countries. *Food Policy* 31, 1–13. doi: 10.1016/j.foodpol.2005.06.006

Garner, E., and De la O Campos, A. P. (2014). *Identifying the family farm. An informal discussion of the concepts and definitions*.

Glover, D., and Kusterer, K. (2016). *Small farmers, big business: Contract farming and rural development*. Springer. Berlin

Goswami, S., Choudhary, H., and Bisht, A. (2017). Factors influencing crop diversification as a tool to twofold farmers' earnings in Uttarakhand. *Indian J. Econ. Dev.* 13, 228–231. doi: 10.5958/2322-0430.2017.00070.1

Gouvernement du Canada (2014). Government of Canada. Language selection - Agriculture and Agri-Food Canada / Sélection de la langue - Agriculture et Agroalimentaire Canada. Available at: https://agriculture.canada.ca/en/agricultural-production/soil-and-land/soil-management/flexibility-no-till-and-reduced-till-systems-ensures-success-long-term

Gouvernement du Canada (2020). Government of Canada. Language selection - Agriculture and Agri-Food Canada / Sélection de la langue - Agriculture et Agroalimentaire Canada. Available at: https://agriculture.canada.ca/en/environment/climate-change/climate-scenarios-agriculture

Government of Canada (2022). Growing and raising costs for farmers. Available at: https://www.statcan.gc.ca/o1/en/plus/2413-growing-and-raising-costs-farmers

Government of Canada, S. C. (2023, September 18). Industrial product and raw materials price indexes, August 2023. The Daily, Available at: https://www150.statcan.gc.ca/n1/daily-quotidien/230918/dq230918a-eng.htm

Government of Ontario (2022, September 16). Cover crops: Adaptation and use of cover crops. ontario.ca. https://www.ontario.ca/page/cover-crops-adaptation-and-use-cover-crops

Guest, G., Namey, E., and Mitchell, M. (2013). *Participant observation*. SAGE Publications, Ltd, Newcastle upon Tyne

Ha, T., Bosch, O. J. H., and Nguyen, N. C. (2016). Practical contributions of the systems-based evolutionary learning laboratory to knowledge and stakeholder management. *Syst. Pract. Action Res.* 29, 261–275. doi: 10.1007/s11213-015-9363-2

Hammer, K., Arrowsmith, N., and Gladis, T. (2003). Agrobiodiversity with emphasis on plant genetic resources. *Naturwissenschaften* 90, 241–250. doi: 10.1007/s00114-003-0433-4

Han, G., and Niles, M. T. (2023). An adoption spectrum for sustainable agriculture practices: a new framework applied to cover crop adoption. *Agric. Syst.* 212:103771. doi: 10.1016/j.agsy.2023.103771

Handford, M., and Gee, J. P. (Eds.). (2013). *The Routledge handbook of discourse analysis*. Routledge. London

Harris, D. R., and Fuller, D. Q. (2014). "Agriculture: definition and overview" in *Encyclopedia of global archaeology*. ed. C. Smith (New York, NY: Springer)

Hernández-Jover, M., Gilmour, J., Schembri, N., Sysak, T., Holyoake, P. K., Beilin, R., et al. (2012). Use of stakeholder analysis to inform risk communication and extension strategies for improved biosecurity amongst small-scale pig producers. *Prev. Vet. Med.* 104, 258–270. doi: 10.1016/j.prevetmed.2011.12.006

Hodge, B. (2017). "Discourse analysis" in *The Routledge handbook of systemic functional linguistics*. eds. T. Bartlett and G. O'Grady (London: Routledge), 544–556.

Hodgson, G. M. (2006). What are institutions? *J. Econ. Issues* 40, 1–25.

Hoffman, M., Lubell, M., and Hillis, V. (2014). Linking knowledge and action through mental models of sustainable agriculture. *Proc. Natl. Acad. Sci.* 111, 13016–13021. doi: 10.1073/pnas.1400435111

Hofmann, N. (2015). Conventional tillage: How conventional is it. Statistics Canada. Retrieved from, Available at: http://www.statcan.gc.ca/pub/16-002-x/2008003/article/10688-eng.htm.

Hoppe, R. A. (2010). *Small farms in the United States: Persistence under pressure*. Diane Publishing. Collingdale, PA

Hubert, B., and Ison, R. (2017). "Systems thinking: towards transformation in praxis and situations" in *Sustainable intensification in smallholder agriculture*. eds. I. Oborn, B. Vanlauwe, M. Phillips, R. Thomas, W. Brooijmans and K. Atta-Krah (London: Routledge), 115–129.

Ikerd, J. E. (1990). Agriculture's search for sustainability and profitability. *J. Soil Water Conserv.* 45, 18–23.

Isaac, M. E., Isakson, S. R., Dale, B., Levkoe, C. Z., Hargreaves, S. K., Méndez, V. E., et al. (2018). Agroecology in Canada: towards an integration of agroecological practice, movement, and science. *Sustain. For.* 10:3299. doi: 10.3390/su10093299

Jansen, T., Srinivasan, S., and Akram-Lodhi, A. H. (2023). "Impervious odds and complicated legacies: young People's pathways into farming in Ontario, Canada" in *Becoming a young farmer: Young People's pathways into farming: Canada, China, India and Indonesia* (Cham: Springer International Publishing), 93–118.

Kanter, D. R., Musumba, M., Wood, S. L., Palm, C., Antle, J., Balvanera, P., et al. (2018). Evaluating agricultural trade-offs in the age of sustainable development. *Agric. Syst.* 163, 73–88. doi: 10.1016/j.agsy.2016.09.010

Karali, E., Brunner, B., Doherty, R., Hersperger, A., and Rounsevell, M. (2014). Identifying the factors that influence farmer participation in environmental management practices in Switzerland. *Hum. Ecol.* 42, 951–963. doi: 10.1007/s10745-014-9701-5

Kragt, M. E., and Robertson, M. J. (2014). Quantifying ecosystem services trade-offs from agricultural practices. *Ecol. Econ.* 102, 147–157. doi: 10.1016/j.ecolecon.2014.04.001

Kremen, C., and Miles, A. (2012). Ecosystem services in biologically diversified versus conventional farming systems: benefits, externalities, and trade-offs. *Ecol. Soc.* 17:25. doi: 10.5751/ES-05035-170440

Kruger, D. H. M., Fourie, J. C., and Malan, A. P. (2013). *Cover crops with biofumigation properties for the suppression of plant-parasitic nematodes: A review*. South African Journal of Enology and Viticulture, Vol. 34.

Kuehne, G., Llewellyn, R., Pannell, D. J., Wilkinson, R., Dolling, P., Ouzman, J., et al. (2017). Predicting farmer uptake of new agricultural practices: a tool for research, extension and policy. *Agric. Syst.* 156, 115–125. doi: 10.1016/j.agsy.2017.06.007

Kumar, D., Singh, B. P., and Kumar, P. (2004). An overview of the factors affecting sugar content of potatoes. *Ann. Appl. Biol.* 145, 247–256. doi: 10.1111/j.1744-7348.2004.tb00380.x

Lehman, R. M., Cambardella, C. A., Stott, D. E., Acosta-Martinez, V., Manter, D. K., Buyer, J. S., et al. (2015). Understanding and enhancing soil biological health: the solution for reversing soil degradation. *Sustain. For.* 7, 988–1027. doi: 10.3390/su7010988

Levy, M. A., Lubell, M. N., and McRoberts, N. (2018). The structure of mental models of sustainable agriculture. *Nat. Sustain.* 1, 413–420. doi: 10.1038/s41893-018-0116-y

Li, H., Zhang, Y., Sun, Y., Liu, P., Zhang, Q., Wang, X., et al. (2023). Long-term effects of optimized fertilization, tillage and crop rotation on soil fertility, crop yield and economic profit on the loess plateau. *Eur. J. Agron.* 143:126731. doi: 10.1016/j.eja.2022.126731

Liang, K., Qi, J., Liu, E. Y., Jiang, Y., Li, S., and Meng, F. R. (2019). Estimated potential impacts of soil and water conservation terraces on potato yields under different climate conditions. *J. Soil Water Conserv.* 74, 225–234. doi: 10.2489/jswc.74.3.225

Liu, T., Bruins, R. J., and Heberling, M. T. (2018). Factors influencing farmers' adoption of best management practices: a review and synthesis. *Sustain. For.* 10:432. doi: 10.3390/su10020432

Lobell, D. B., Schlenker, W., and Costa-Roberts, J. (2011). Climate trends and global crop production since 1980. *Science* 333, 616–620. doi: 10.1126/science.1204531

Loureiro, M. L., and Hine, S. (2002). Discovering niche markets: a comparison of consumer willingness to pay for local (Colorado grown), organic, and GMO-free products. *J. Agric. Appl. Econ.* 34, 477–487. doi: 10.1017/S1074070800009251

Matson, P. A., Parton, W. J., Power, A. G., and Swift, M. J. (1997). Agricultural intensification and ecosystem properties. *Science* 277, 504–509. doi: 10.1126/science.277.5325.504

McLaughlin, A., and Mineau, P. (1995). The impact of agricultural practices on biodiversity. *Agric. Ecosyst. Environ.* 55, 201–212. doi: 10.1016/0167-8809(95)00609-V

Meadows, D. H. (1999). *Leverage points: Places to intervene in a system*. Sustainability Institute. Hartland, VT

Meadows, D. H. (2008). *Thinking in systems: a primer*. Chelsea Green Publishing. Chelsea

Miller, J. (2014). *Farmer adoption of best management practices using incentivized conservation programs*. The University of Vermont and State Agricultural College. Burlington, VT

Ministry of Forests, Lands, Natural Resource Operations and Rural Development (2021). Environmental stewardship and sustainability report. Available at: https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/bc-timber-sales/environmental-stewardship-sustainability/bcts_sustainability_report_2021.pdf

Monat, J. P., and Gannon, T. F. (2015). What is systems thinking? A review of selected literature plus recommendations. *Am. J. Sci.* 4, 11–26. doi: 10.5923/j.ajss.20150401.02

Moonen, A. C., and Barberi, P. (2004). Size and composition of the weed seedbank after 7 years of different cover-crop-maize management systems. *Weed Res.* 44, 163–177. doi: 10.1111/j.1365-3180.2004.00388.x

Morris, C., and Winter, M. (1999). Integrated farming systems: the third way for European agriculture? *Land Use Policy* 16, 193–205. doi: 10.1016/S0264-8377(99)00020-4

Mozzato, D., Gatto, P., Defrancesco, E., Bortolini, L., Pirotti, F., Pisani, E., et al. (2018). The role of factors affecting the adoption of environmentally friendly farming practices: can geographical context and time explain the differences emerging from literature? *Sustain. For.* 10:3101. doi: 10.3390/su10093101

Novita, E., and Ilsan, M. (2016). Sustainability analysis of potato farming system at sloping land in Gowa regency, South Sulawesi. *Agri. Agricult. Sci. Procedia* 9, 4–12.

NRC (National Research Council) (2003). *Frontiers in agricultural research. Food, health, environment, and communities*. Washington DC: National Academy Press.

Ontario Ministry of Agriculture (2018). "Food and rural affairs" in *New horizons: Ontario's agricultural soil health and conservation strategy* (Guelph, ON: Ontario Ministry of Agriculture, Food and Rural Affairs)

Ontario Potato Board Membership (2024). Available at: https://www.ontariopotatoes.ca/membership-1#:~:text=The%20Ontario%20Farm%20Products%20Marketing,more%20of%20potatoes%20in%20Ontario

Ontario Seed Potato Growers Association (2023). Supporting Ontario Seed Potato Growers Association. Available at: https://ospga.ca/

OMAFRA (2017). Agronomy guide for field crops: Chapter 14, Integrated Pest Management and Protecting Natural Enemies and Pollinators. In: Chris Brown (Ed.), *Agronomy guide for field crops, Publication 811*, OMAFRA, Ontario Ministry of Agriculture and Food

Plummer, R., Spiers, A., Summer, R., and FitzGibbon, J. (2008). The contributions of stewardship to managing agro-ecosystem environments. *J. Sustain. Agric.* 31, 55–84. doi: 10.1300/J064v31n03_06

Policonomics (2012). *Structure, conduct, performance paradigm*. Policonomics. Madrid, Spain.

Posthumus, H., de Steenhuijsen-Piters, B., Dengerink, J., and Vellema, S. (2018). *Food systems: from concept to practice and vice versa*. Wageningen University & Research Wageningen

Power, A. G. (2010). Ecosystem services and agriculture: tradeoffs and synergies. *Philos. Trans. R. Soc. B* 365, 2959–2971. doi: 10.1098/rstb.2010.0143

Prokopy, L. S., Floress, K., Klotthor-Weinkauf, D., and Baumgart-Getz, A. (2008). Determinants of agricultural best management practice adoption: evidence from the literature. *J. Soil Water Conserv.* 63, 300–311. doi: 10.2489/jswc.63.5.300

Qualman, D., and Tait, F. (2004). *The farm crisis, bigger farms and the myths of" competition" and" efficiency"*. Canadian Centre Policy Alternatives Ottawa, ON.

Richards, T. J., and Rickard, B. (2020). COVID-19 impact on fruit and vegetable markets. *Can. J. Agric. Econ.* 68, 189–194. doi: 10.1111/cjag.12231

Robertson, G. P., and Swinton, S. M. (2005). Reconciling agricultural productivity and environmental integrity: a grand challenge for agriculture. *Front. Ecol. Environ.* 3, 38–46. doi: 10.1890/1540-9295(2005)003[0038:RAPAEI]2.0.CO;2

Rose, D. C., Keating, C., and Morris, C. (2018). *Understanding how to influence farmers' decision-making behavior: A social science literature review*. University of East Anglia.

Rotz, S., and Fraser, E. D. (2015). Resilience and the industrial food system: analyzing the impacts of agricultural industrialization on food system vulnerability. *J. Environ. Stud. Sci.* 5, 459–473. doi: 10.1007/s13412-015-0277-1

Senge, P. M. (1997). The fifth discipline. *Meas. Bus. Excell.* 1, 46–51. doi: 10.1108/eb025496

Shen, J., Li, S., Liang, Z., Liu, L., Li, D., and Wu, S. (2020). Exploring the heterogeneity and nonlinearity of trade-offs and synergies among ecosystem services bundles in the Beijing-Tianjin-Hebei urban agglomeration. *Ecosyst. Serv.* 43:101103. doi: 10.1016/j.ecoser.2020.101103

Shock, C. C., Pereira, A. B., and Eldredge, E. P. (2007). Irrigation best management practices for potato. *Am. J. Potato Res.* 84, 29–37. doi: 10.1007/BF02986296

Sørensen, C. G., Madsen, N. A., and Jacobsen, B. H. (2005). Organic farming scenarios: operational analysis and costs of implementing innovative technologies. *Biosyst. Eng.* 91, 127–137. doi: 10.1016/j.biosystemseng.2005.03.006

Sparling, D., and Thomspon, S. (2011). *Competitivesness of the Canadian Agri-food sector*. Ottawa: The Canadian Agri-Food Policy Institute.

Statistics Canada (2024). Table 32-10-0358-01 Area, production and farm value of potatoes. doi: 10.25318/3210035801-eng

Standards Council of Canada (2021). *Organic production systems: General principles and management standards*. Ottawa; Canadian General Standards Board.

Streeton, R., Cooke, M., and Campbell, J. (2004). Researching the researchers: using a snowballing technique. *Nurse Res.* 12, 35–47. doi: 10.7748/nr2004.07.12.1.35.c5929

Sumberg, J., and Giller, K. E. (2022). What is 'conventional'agriculture? *Glob. Food Sec.* 32:100617. doi: 10.1016/j.gfs.2022.100617

Thrupp, L. A. (2000). Linking agricultural biodiversity and food security: the valuable role of agrobiodiversity for sustainable agriculture. *Int. Aff.* 76, 265–281. doi: 10.1111/1468-2346.00133

Tilman, D. (1999). Global environmental impacts of agricultural expansion: the need for sustainable and efficient practices. *Proc. Natl. Acad. Sci.* 96, 5995–6000. doi: 10.1073/pnas.96.11.5995

Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R. L., and Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature* 418, 671–677. doi: 10.1038/nature01014

Tilman, D., Reich, P. B., Knops, J., Wedin, D., Mielke, T., and Lehman, C. (2001). Diversity and productivity in a long-term grassland experiment. *Science* 294, 843–845. doi: 10.1126/science.1060391

Torresen, K. S., Skuterud, R., Tandsaether, H. J., and Hagemo, M. B. (2003). Long-term experiments with reduced tillage in spring cereals. I. Effects on weed flora, weed seedbank and grain yield. *Crop Prot.* 22, 185–200. doi: 10.1016/S0261-2194(02)00145-X

Tscharntke, T., Klein, A. M., Kruess, A., Steffan-Dewenter, I., and Thies, C. (2005). Landscape perspectives on agricultural intensification and biodiversity—ecosystem service management. *Ecol. Lett.* 8, 857–874. doi: 10.1111/j.1461-0248.2005.00782.x

Urwin, K., and Jordan, A. (2008). Does public policy support or undermine climate change adaptation? Exploring policy interplay across different scales of governance. *Glob. Environ. Chang.* 18, 180–191. doi: 10.1016/j.gloenvcha.2007.08.002

USDA Climate Hub. (n.d.). Field crops. Field Crops | USDA Climate Hubs. Available at: https://www.climatehubs.usda.gov/commodity/field-crops

VanderZaag, P. (2010). Toward sustainable potato production: experience with alternative methods of pest and disease control on a commercial potato farm. *Am. J. Potato Res.* 87, 428–433. doi: 10.1007/s12230-010-9161-4

Vasileiadis, V. P., Froud-Williams, R. J., and Eleftherohorinos, I. G. (2007). Vertical distribution, size and composition of the weed seedbank under various tillage and herbicide treatments in a sequence of industrial crops. *Weed Res.* 47, 222–230. doi: 10.1111/j.1365-3180.2007.00564.x

Wall, E., and Smit, B. (2005). Climate change adaptation in light of sustainable agriculture. *J. Sustain. Agric.* 27, 113–123. doi: 10.1300/J064v27n01_07

Weber, M., and Alberta, I. (2017). Understanding farmer motivation and attitudes regarding the adoption of specific soil best management practices. Summary and Recommendations 36p. Available at: https://www.farmfoodcareon.org/wpcontent/uploads/2017/10/FCC-Adoption-Behavior-Summary-and-Recommendations.pdf

Woodall, P., and Lynn, B. C., (2011) *Monopoly meat: A discussion on the market concentration in relation to meat packing*. George Washington University, Washington, DC

Work, T. M., Kezis, A. S., and True, R. H. (1981). *Factors determining potato chipping quality*. Life Sciences and Agriculture Experiment Station, University of Maine at Orono. Orono, ME

Xu, X., Liu, J., Tan, Y., and Yang, G. (2021). Quantifying and optimizing agroecosystem services in China's Taihu Lake Basin. *J. Environ. Manag.* 277:111440. doi: 10.1016/j.jenvman.2020.111440

Yiridoe, E. K., Atari, D. O. A., Gordon, R., and Smale, S. (2010). Factors influencing participation in the Nova Scotia environmental farm plan program. *Land Use Policy* 27, 1097–1106. doi: 10.1016/j.landusepol.2010.02.006

Zhang, W., Ricketts, T. H., Kremen, C., Carney, K., and Swinton, S. M. (2007). Ecosystem services and dis-services to agriculture. *Ecol. Econ.* 64, 253–260. doi: 10.1016/j.ecolecon.2007.02.024