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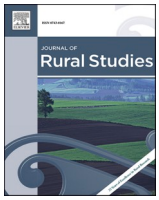

Beyond cost-benefit: Governance, trust, and support in the adoption of digital agriculture technologies in Alberta, Canada

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ABSTRACT

Digital agriculture technologies (DATs) promise to enhance productivity, sustainability, and resilience in farming, yet their adoption remains uneven across Canada. This study investigates the socio-technical dimensions of DAT adoption in Alberta's crop and cattle sectors, a key agricultural hub within national and global food systems. Drawing on semi-structured interviews with 14 stakeholders and guided by the Technology Acceptance Model (TAM), the analysis explores producers' decision-making behaviors, trust dynamics, and the perceptions of service providers, industry, and government actors. Findings reveal that adoption is shaped not only by cost–benefit considerations but also by trust in data governance, alignment with operational realities, and access to contextualized agronomic support. Persistent barriers include limited data literacy, interoperability challenges, and inadequate post-adoption support, while opportunities lie in AI-enabled tools, peer learning, and co-designed service models. Policy recommendations highlight the importance of region-specific demonstration projects, the development of a national ag-data ethics charter, and greater investment in knowledge-sharing infrastructure. By centering producer perspectives and systemic constraints, this study contributes to the design of inclusive and scalable strategies for advancing digital agriculture in Alberta and beyond.

1. Introduction

Digital agriculture technologies (DATs) are increasingly promoted as essential tools for enhancing agricultural productivity, sustainability, and resilience. These technologies support evidence-based decision making through remote sensing, automated machinery, internet-connected sensors, and data-driven analytics, and they are widely expected to help producers optimize resource use, respond to climate pressures, and address labour constraints (Rose and Chilvers, 2018; Klerkx et al., 2019). Recent advances in data collection, storage, and processing have expanded the scope of precision agriculture beyond traditional field-variability approaches, enabling more detailed monitoring of soils, crops, and nutrient applications and, in many cases, improving profitability (Ishaque et al., 2024). However, the use of decision support tools in farming remains uneven, and uptake often does not follow a linear relationship between technological capability and user adoption (Rose et al., 2018).

A growing body of research emphasizes that digitalization in agriculture is not solely a technical transformation; it is a socio-technical process shaped by social, economic, ethical, and institutional conditions (Klerkx and Leeuwis, 2009; Bronson, 2019; Rotz et al., 2019; Phillips et al., 2019; Soma and Nuckchady, 2021; Duncan, 2023; Fulton et al., 2021). Adoption decisions reflect structural factors such as farm size, capital and connectivity, human factors including skills, education and attitudes, and perceived value in terms of productivity gains or profitability (Aubert et al., 2012; Daberkow and McBride, 2003; Pierpaoli et al., 2013; Schimmelpfennig, 2016; Paustian and Theuvsen, 2017; Pathak et al., 2019; Bolfe et al., 2020;Giua et al., 2022; Say et al., 2018; Pivoto et al., 2019). Despite the agronomic potential of digital tools, adoption is constrained by concerns about data governance, proprietary or incompatible systems, and the availability of trusted advisory support (Bronson, 2019; Wiseman et al., 2019). Studies across Europe, North America, and Oceania further show that uncertainty around data ownership, privacy, and interoperability can limit farmer trust and reduce the perceived usefulness of DATs (Carolan, 2017; van der Burg et al., 2019).

Digital agriculture adoption has been widely examined across diverse contexts, including Europe (Rose et al., 2018; Klerkx et al., 2019), Australia and New Zealand (Eastwood and Dela Rue, 2017), the United States (Daberkow and McBride, 2003), Germany (Paustian and

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Theuvsen, 2017), Brazil (Bolfe et al., 2020), and Asia (Li et al., 2022). Despite this broad geographic coverage, much of the existing research continues to focus on single stakeholder groups. Many studies emphasize primarily economic or technical determinants of adoption. Others centre on precision agriculture tools rather than the broader governance, interoperability, and trust-related issues that increasingly shape digital agriculture systems. What remains insufficiently addressed is how multiple actors within an agricultural ecosystem make sense of digital technologies, negotiate data governance, and align (or fail to align) expectations about value, risk, and advisory support. As a result, there is lack a comprehensive understanding of how socio-technical dynamics shape adoption across an entire agricultural ecosystem.

In Canada, research on digital agriculture remains comparatively limited. Existing work highlights issues such as limited accessibility, low usability, and ambiguous value propositions in both crop and livestock production (Steele, 2017; Tse et al., 2018; Duncan, 2018; Mitchell et al., 2020; Makinde et al., 2022). Very few studies examine how different actors within the agricultural ecosystem interpret, evaluate, and engage with digital tools. Duncan's (2018) work shows that producers often rely heavily on vendors for training and technical support, contributing to inconsistent or incomplete adoption. Khannal et al. (2025) highlight the lack of on-farm adoption support and farmer-centric data governance as latent barriers to digital technology uptake. Makinde et al. (2022) provide insights from livestock producers, but we still know little about how producers, AgTech service providers, agronomists, and government stakeholders collectively understand the broader determinants of DAT adoption.

This study responds to these gaps by examining the socio-technical and governance dimensions of DAT adoption in Alberta through qualitative analysis guided by an extended Technology Acceptance Model (TAM). By incorporating constructs such as perceived trust (PT) and external institutional factors, and by drawing on interviews with producers, service providers, industry stakeholders, and government representatives, the study contributes a grounded, multi-perspective account of digital agriculture adoption in Alberta—a region whose environmental variability, export orientation, and rapidly developing AgTech ecosystem mirror many structural challenges observed globally. Alberta is a significant agricultural region and a major contributor to global agri-food markets, producing Canada's largest share of beef and its second-largest share of crop output (Kulshreshtha et al., 2012; Statistics Canada, 2024). The province exported a record 17.5 billion dollars in agri-food products in 2024, underscoring its importance to national and international supply chains (Government of Alberta, 2024). Its diverse farming systems, export orientation, and rapidly expanding AgTech ecosystem make it an ideal setting for exploring the opportunities and challenges associated with digital agriculture.

By examining the perspectives of producers, agronomists, AgTech firms, and government representatives, this study advances understanding of how digital agriculture adoption unfolds in practice. It integrates governance and trust considerations into a socio-technical interpretation of adoption and provides insights relevant not only to Alberta but also to other regions facing similar pressures of technological innovation, environmental change, and market competitiveness. The findings support efforts to design more inclusive, effective, and context-sensitive digital agriculture strategies.

Guided by the gaps identified in the literature and the need for a multi-stakeholder understanding of digital agriculture adoption, this study addresses the following research questions.

a. How do producers, agronomists, AgTech providers, and government stakeholders perceive digital agriculture technologies, and which factors shape their attitudes, intentions, and actual use?
b. In what ways does the pace and direction of industry-driven innovation align or misalign with producer readiness, and how do barriers such as cost, interoperability, usability, and access to advisory support contribute to this gap?
c. How do data governance issues, including data ownership, privacy, transparency, and control, influence producer trust and their decisions to adopt or reject digital agriculture technologies?

2. Theoretical framework

The rapid advancement and integration of digital technologies into both an individual's private and professional lives in the past decades, has resulted in a proliferation of research examining factors that lead to successful digital technology adoption. Several prominent theories and frameworks have been developed to explain technology adoption. These include the Diffusion of Innovations Theory (Rogers, 1962, 2003), Social Cognitive Theory (Bandura, 1986), Model of PC Utilization (Thompson et al., 1991), Technology Acceptance Model (TAM) (Chuttur, 2009), Theory of Planned Behavior (Ajzen, 1991), and Unified Theory of Acceptance and Use of Technology (Venkatesh et al., 2003). Among these, TAM is considered one of the most influential and empirically validated frameworks for understanding technology adoption and has been found to be a "robust, powerful, and parsimonious model for predicting user acceptance" (Marangunić and Granić, 2015; Venkatesh and Davis, 2000, p186).

TAM was originally developed by Davis (1985), grounded in the Theory of Reasoned Action and other related studies (Fishbein and Ajzen, 1975) and was initially conceptualized as a quantitative model that would predict technology acceptance. Davis hypothesized that a user's attitude was a major determinant of whether they would accept or reject a technology. And the user's attitude toward a technology along with their intention to use it, depends on two primary factors: (1) Perceived Usefulness (PU): The degree to which an individual believes that using a particular system would enhance their job performance; and (2) Perceived Ease of Use (PEOU): The extent to which a person believes that using the system would be free of extra effort. These cognitive beliefs shape the user's attitude toward the technology, which then influences behavioral intention and actual usage. Fig. 1 depicts this extended conceptual model illustrating how external factors influence PU, PEOU, and PT which then shape user attitudes, behavioral intentions, and technology adoption.

Since its inception and with the advancement of technology adoption, TAM has evolved substantially, with scholars adapting it to include contextual variables that capture trust, experience, and environmental constraints. Extensions such as TAM2, TAM3, and the Unified Theory of Acceptance and Use of Technology highlight how social norms, facilitating conditions, and perceived risk interact with Perceived Usefulness and Perceived Ease of Use to influence technology adoption behavior (Venkatesh and Davis, 2000; Venkatesh et al., 2003). Recognizing this adaptability of TAM, and the evolving nature of technology adoption, we expanded our analysis of the adoption behavior of Alberta's crop and cattle producers to include Perceived Trust—the belief that the technology is reliable, and the provider is dependable. Perceived Trust reflects an individual's belief that a technology and its provider are reliable, competent and ethically sound (Pavlou, 2003). Furthermore, a meta-analysis by Wu et al. (2011) demonstrated that incorporating trust enhances TAM's predictive capability regarding user acceptance of technology. In digital agriculture, where concerns about data privacy, ownership, and governance are widespread, trust becomes an important determinant of willingness to adopt (Wu et al., 2011). Therefore, we integrate PT to capture how beliefs about the credibility and dependability of data systems influence attitudes and intentions toward technology adoption.

External factors related to institutional, infrastructural and sociopolitical influences also shape users' cognitive responses, specifically their perceptions of a technology's ease of use and usefulness (Davis, 1989, 1993). In the context of Alberta, these factors include government policies, data governance frameworks, extension services, industry-led initiatives, and broader infrastructural conditions such as internet connectivity and interoperability standards. These external factors serve as

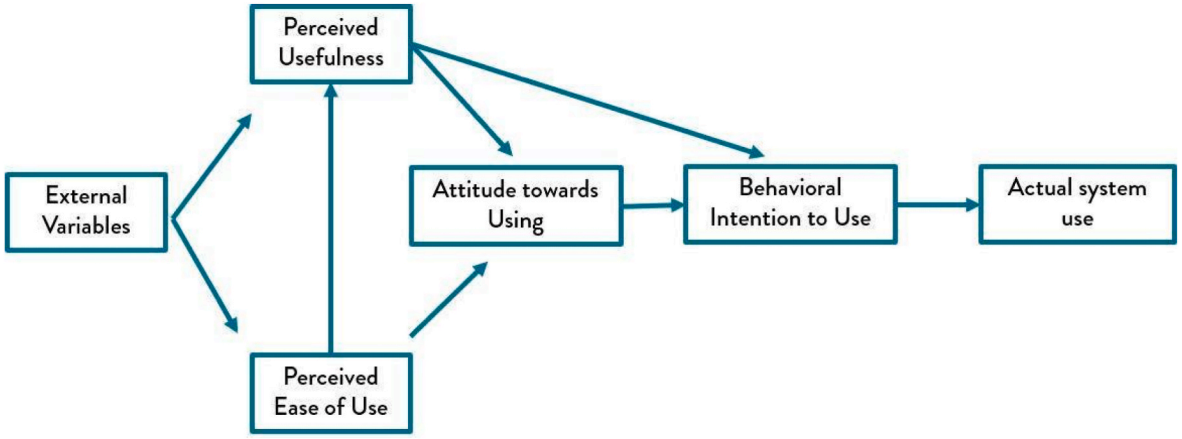

Fig. 1. Technology acceptance model (Source: Castiblanco Jimenez et al., 2021).

both challenges and opportunities to understand how cognitive beliefs influence attitudes and behaviors. These are particularly applicable to rural and agricultural contexts, where adoption decisions are made within a complex web of policy, community, and market influences.

TAM has dominated acceptance research given that it has reliably explained variance in intention to use. It is easy to handle, versatile and generalizable (Vogelsang et al., 2013). However, research has also shown that TAM may not be robust enough to explain complex decision processes or predict actual behavior (Bagozzi, 2007). Given some shortcomings of the quantitative approach used in TAM, recent scholarship has called for its qualitative adaptation to leverage the variables from TAM to gain deeper insights into user experience, especially in socio-technical systems where behavioral intentions are mixed with institutional and cultural contexts (Vogelsang et al., 2013; Luo et al., 2019; Vereenooghe et al., 2021). Following this qualitative line of work, our study applies TAM qualitatively to examine how producers, agronomists, industry professionals, and government actors evaluate and engage with digital agriculture technologies in Alberta. While frameworks such as Actor Network Theory (Latour, 2005) and Social Practice Theory (Shove et al., 2012) offer valuable perspectives on technology adoption, they often emphasize distributed agency and practice-oriented transformation rather than individual cognition and decision-making. TAM complements these approaches with the addition of cognitive and affective processes. In the context of digital agriculture, examining both – human perception and broader socio-technical context, allows us to integrate behavioral and systemic dimensions of adoption.

This conceptual framework guides our thematic analysis, enabling us to situate our qualitative interview data within a theoretically grounded and empirically relevant framework to understand digital agriculture technology adoption.

3. Methodological approach

This study employs a qualitative research design to investigate the dynamics of adoption of DATs and use of data in farming decisions by studying the attitudes and perceptions of diverse stakeholders in Alberta's crop and cattle sectors. Given the complexity and evolving nature of DATs, in-depth, semi-structured interviews were chosen as the primary method of data collection. Previous research has predominantly relied on survey-based methodologies, which, while useful for identifying broad trends, often fail to capture the subtleties of user experience and the dynamic nature of technology adoption in agriculture. Recognizing this gap, the current study focused on qualitative insights to better understand the lived realities of those navigating the transition to digital systems. In particular, the slow uptake of DATs, due in part to their technical complexity and the analytical skills they demand, suggested the importance of examining both ends of the adoption equation i.e., the producers who implement these tools and the technology service providers, industry and government stakeholders who support their use.

3.1. Data collection

Participants were recruited using a combination of purposive, convenience, and snowball sampling to ensure coverage of the major stakeholder groups involved in digital agriculture in Alberta. The study began with technology service providers who were accessible through prior collaborations and professional networks and who play a central role in the provincial AgTech ecosystem. Service providers were deliberately selected as initial contacts because they interact with a wide range of producers and industry actors, making them well positioned to identify additional participants with relevant experience.

Snowball sampling was then used to reach producers, agronomists, industry stakeholders, and government actors. This approach was particularly appropriate given the interconnected nature of Alberta's agricultural networks, where trusted referrals facilitate access to participants who might otherwise be difficult to reach. Recruitment aimed to capture variation in farm size, production type (crop, cattle, and mixed operations), years of experience, and institutional roles. Participants were approached by email or phone, provided with study information, and invited to participate voluntarily. All respondents were located within Alberta and recruited between July 2024 and February 2025.

In total, 14 semi-structured interviews were conducted until saturation was reached. Interviews were conducted between July 2024 and February 2025. Each interview lasted 35–50 min. The participants were categorized into three groups: producers, technology service providers, and government officials. The data was collected from five producers, four technology service providers, three industry stakeholders, and two representatives from the provincial government's agriculture departments. Producers included represent a range of scales (120–17,500 acres) and cattle operations (50–600 head), while service providers collectively cover 100,000 to over 3 million acres, thereby offering ecosystem-wide perspectives.

Data saturation was assessed iteratively throughout the interview process. After approximately twelve interviews, no new substantive themes were emerging regarding interoperability barriers, perceived usefulness, uncertainty about return on investment, trust in data governance, or support needs. The final two interviews were conducted to confirm thematic stability across stakeholder categories, including both producers and non-producers. These final interviews yielded only repetitions or minor variations of previously identified concepts, indicating that saturation, defined as the point at which additional data fail

to generate new insights, had been reached. A sample of fourteen interviews is appropriate for this qualitative study, as it aligns with empirical evidence showing that thematic saturation is often reached within a range of nine to seventeen interviews (Hennink and Kaiser, 2022). This justification is particularly relevant given that the participant group is relatively homogenous in its engagement with digital agriculture and the study focuses on clearly defined research objectives—conditions under which prior studies have consistently found saturation to occur. Furthermore, this study does not aim for representativeness. Instead, following qualitative research standards, it seeks depth of insight from strategically positioned actors.

A sample overview is given in Table 1.

Three versions of the interview guide (Appendix-I) were developed, each tailored slightly to reflect the specific roles and experiences of the respondent groups while focusing on ensuring clarity, relevance, and methodological rigour. Interview questions addressed a range of themes, including.

i. Demographics – participant background, years of experience, and role in agriculture.
ii. Farm or Service Scope – size of farmland operated or serviced and type of production (crop, cattle, or both).
iii. Perceptions of DAT Usefulness – attitudes toward the value and relevance of digital technologies.
iv. Data Collection – types of data collected using DATs and frequency of collection.
v. Decision-Making – how data informs operational and business decisions.
vi. Technical Support Needs – reliance on agronomists, advisors, or tech service providers.
vii. Adoption Experience – personal or observed experiences with adopting DATs.
viii. Challenges and Barriers – financial, technical, or organizational hurdles in adoption.
ix. Outlook – expectations regarding the growth and impact of DATs in agriculture.
x. Policy and Data Governance – views on regulation, data ownership, and the need for government support. These questions were open-ended to allow for rich, detailed responses and the emergence of unexpected insights.

Table 1
Overview of interview participants.

#	Participant ID	Category	Type of Operation	Acres Farmed/ Serviced	Years of Experience
1	CA-P1 (Feb 10, 2025)	Producer	Crop Production	17,500	30
2	CW-SP1 (Aug 8, 2024)	Service Provider	AgTech	3,000,000	25
3	CL-AC1 (Jan 3, 2025)	Industry stakeholder	Ag Communication	NA	15
4	GD-SP2 (Aug 28, 2024)	Service Provider	AgTech	1,400,000	20
5	HB-G1 (Jan 17, 2025)	Government	Policy Research	NA	2
6	JC-P2 (Sep 4, 2024)	Producer	Crop Production	120	8
7	JS-P3 (Nov 7, 2024)	Producer	Crop and Cattle	10,000	30
8	MF-SP3 (Aug 14, 2024)	Service Provider	Crop Production	500	8
9	PG-SP4 (Aug 26, 2024)	Service Provider	AgTech	100,000	12
10	SL-P4 (Feb 11, 2025)	Producer	Crop Production	365	20
11	TG-P5 (Feb 11, 2025)	Producer	Crop and Cattle	320	10
12	RM-AF (July 3, 2025)	Industry stakeholder	Agri Finance	NA	6
13	GF- G2 (July 8, 2025)	Government	Policy Advisory	NA	25
14	MCS-IE (July 10, 2025)	Industry stakeholder	Venture Capital Funder	NA	7

3.2. Thematic analysis

Given its structured and flexible approach in applied research, we used the Framework Analysis method developed by Ritchie and Spencer (1994) to systematically analyze our qualitative data. This method involves five key stages:

1. Familiarization: Immersing ourselves in the data by thoroughly reading interview transcripts to gain an overarching understanding.
2. Identifying a Thematic Framework: Developing a set of themes and sub-themes informed by our research objectives and patterns emerging from the data.
3. Indexing: Systematically applying the thematic framework to the data by coding segments accordingly.
4. Charting: Organizing the coded data into matrices, facilitating the comparison of themes across different participants.
5. Mapping and Interpretation: Analyzing the relationships between themes to derive meaningful insights and interpretations.

By using a mixed inductive-deductive thematic coding approach following Fereday and Muir-Cochrane (2006), we conducted a thematic analysis using the guidelines developed by Braun and Clarke (2006). Following a detailed analysis of the interview transcripts, we carried out the initial round of coding. Initially, a deductive framework guided by existing literature and the research objectives was applied to identify themes relevant to known barriers and facilitators of DAT adoption. This was followed by an inductive phase, during which themes and patterns were allowed to emerge from the data itself.

In this first phase, we inductively generated codes to capture the smallest meaningful units of information within the data. These seventy-two (72) codes and sub-codes reflected participants' experiences, concerns, and perspectives in relation to DAT use. We then reviewed and discussed the preliminary coding collaboratively with the co-authors to ensure coherence and consistency. Following the Framework Analysis method, the codes were charted across participant categories i.e. producers, agronomists/service providers, industry stakeholders, and government representatives, following the framework analysis method. This facilitated both within-case and cross-case comparison, highlighting convergent and divergent viewpoints. Codes were then grouped into broader categories aligned with the extended TAM: perceived usefulness, perceived ease of use, perceived trust, attitudes, and external factors, alongside emergent socio-technical themes such as data governance, knowledge transfer, and institutional support as factors affecting overall behavioural intention to use DATs. We also integrated additional themes such as policy support and industry initiatives as external factors that nudge the attitude of producers towards the adoption of DATs.

Different themes were organized under each component of the extended TAM. This dual approach ensured that the findings remained grounded in participant experiences while also contributing to the broader theoretical understanding of digital technology adoption in agriculture.

4. Results

The structure of the thematic analysis is presented in Fig. 2. The results discussed in the subsequent sections illustrate the dynamics of digital technology adoption, derived from a thematic analysis of data collected from diverse stakeholders, organized in line with the TAM.

4.1. Perceived usefulness

This theme, derived from the TAM, emphasizes the perceived value of DATs in terms of improving productivity, profitability and sustainability of the farming operations. Within this category, three key subthemes were identified: Uncertainty around value and outcomes; effectiveness function and technology; and profit-driven adoption factors.

All participants considered DATs to be useful in automating processing and improving efficiency. However, they raised concerns about the need to upgrade their farm equipment with more data intensive technologies. The uses of DATs mentioned by the respondents could be broadly categorized into precision agriculture and field analysis; farm operations management; market and risk management; and livestock management and farm solutions.

4.1.1. Uncertainty around value and outcomes

A major determinant in the adoption of DATs is producers' perception about their tangible value and the consistency of their outcomes. Uncertainty about the usefulness of DAT emerged as a major barrier to adoption. It can be viewed through the lens of both users and non-users. Users often struggle with the complexity of implementation, including operating new equipment and interpreting data-derived insights, while non-users[1] of certain DATs cite pre-adoption barriers such as cost, unreliable internet connectivity, and lack of time or mental bandwidth to manage the change. These concerns reveal a central friction: many producers remain unsure whether DATs will deliver results proportional to the time, cost, and learning required to adopt them.

This perceived unpredictability is amplified by the difficulty in quantifying direct benefits, which are heavily influenced by environmental factors such as drought or disease outbreaks, especially in livestock. As one service provider put it: *"There might be three years out of ten where there's no benefit—say, during an extreme drought. What benefit was there then? Nothing—the guy might have lost $200 an acre. But in the other seven years, there might be three where the return was $100 an acre … It's no different than asking a farmer, 'What's the rate of return on your fertilizer?"*

In this framing, even for users of DATs, economic outcomes are not guaranteed and often defy short-term evaluation. Further complicating return on investment (ROI) estimation are the indirect benefits—such as better crop uniformity, operational consistency, and improved planning—that may be functionally important but difficult to quantify. As another provider noted, some producers adopt DATs not to maximize yield but to meet specific quality or regulatory goals:

> "We have customers—like seed growers—who say, 'I don't even do this for yield.' They need uniformity and harvestability. So, their motivation is completely different from that of a typical commercial farm."

This diversity in motivations and farm type underscores how perceived usefulness is shaped not just by performance metrics, but by each producer's operational context. For example, one mixed producer managing 10,000 acres and 600 cattle stated: *"In areas with higher yields and more predictability because of moisture, they seem to get a return on investment from variable rate.*[2] *But I'm not sure it's been perfected enough for our region yet."* Such sentiments reflect a geographic dimension to uncertainty, as soil, climate, and market conditions vary across Alberta and beyond. This spatial variability undermines confidence in one-size-fits-all technological solutions, further delaying widespread adoption.

Another key source of uncertainty lies in the fragmented landscape of digital tools. Several participants noted challenges in aligning software platforms with their hardware or data workflows. Despite experimenting with multiple systems, few found options that worked seamlessly with their farm setup. This lack of interoperability, combined with limited support for cost-of-production analysis or offseason planning, has left many producers unconvinced of the value of investing in better data infrastructure. As one participant observed, *"What's the point in cleaning up the data if we're not even sure how to use it to make better financial decisions?"*

In contrast, service providers and agronomists painted a more optimistic picture. Many claimed their clients had realized strong financial returns from tools like soil mapping and variable rate technology (VRT). One agronomist cited internal survey results: *"Most farmers report a three-to-one return on investment, while about 20 to 30 percent say they've seen greater than five-to-one. It really varies, but that curve tells a lot about perceived value."*

Another service provider, who also farms a small farm, provided a concrete breakdown of savings enabled by satellite imagery: *"This harvest, we used satellite imagery to identify the driest parts of our fields and combined those first to avoid drying costs … That's $50* per *acre saved just by avoiding the dryer … even if we save on just one 100-acre field, that's $5000 in savings—more than an 8-to-1 return."*

While such examples demonstrate the potential value of DATs, they also highlight a gap between reported outcomes and broader producer sentiment, suggesting that benefits are often highly context-specific and not easily generalized.

A further layer of skepticism arises when new technologies outpace operational realities. One VRT provider noted that while advancements in information and communication technologies (ICT) have increased the potential of soil sensors and remote monitoring tools, their real-world application remains constrained: *"These systems are more practical in settings like vineyards or orchards … For large-scale farming, it's still a struggle."*

This concern was echoed by others, who pointed to a disconnect between the technologies showcased at agricultural conferences and what is realistically useable on Alberta farms. Many tools are either not designed with large-scale producers in mind or enter the market without viable business models, creating a sense of tech fatigue among farmers. In fast-evolving environments, this creates a paradox: while innovation continues at pace, producer trust and confidence lag, especially when tools don't perform reliably in diverse soil and climatic zones. "*Understanding each operation's business model is key. Agriculture is regional and nuanced. Solutions must be tailored from the ground up, starting with producers and moving to policymakers—not the other way around"*, one participant noted.

Ultimately, the uncertainty surrounding the value of DATs reveals a critical tension in digital agriculture. Producers are not necessarily resistant to innovation, but are wary of tools that lack clear, consistent, and context-sensitive evidence of impact. Without grounded support in demonstrating both direct and indirect outcomes, particularly in financial terms, many remain hesitant to adopt—even when intrigued by the potential.

[1] Non-users here refers to producers who have adopted basic technologies (e.g., GPS and/or autosteer) but not those that involve data collection and analysis.

[2] Variable rate refers to the application of agricultural inputs (e.g., seed, fertilizer, pesticides) at varying rates across a field, based on site-specific conditions such as soil properties, yield potential, or crop needs.

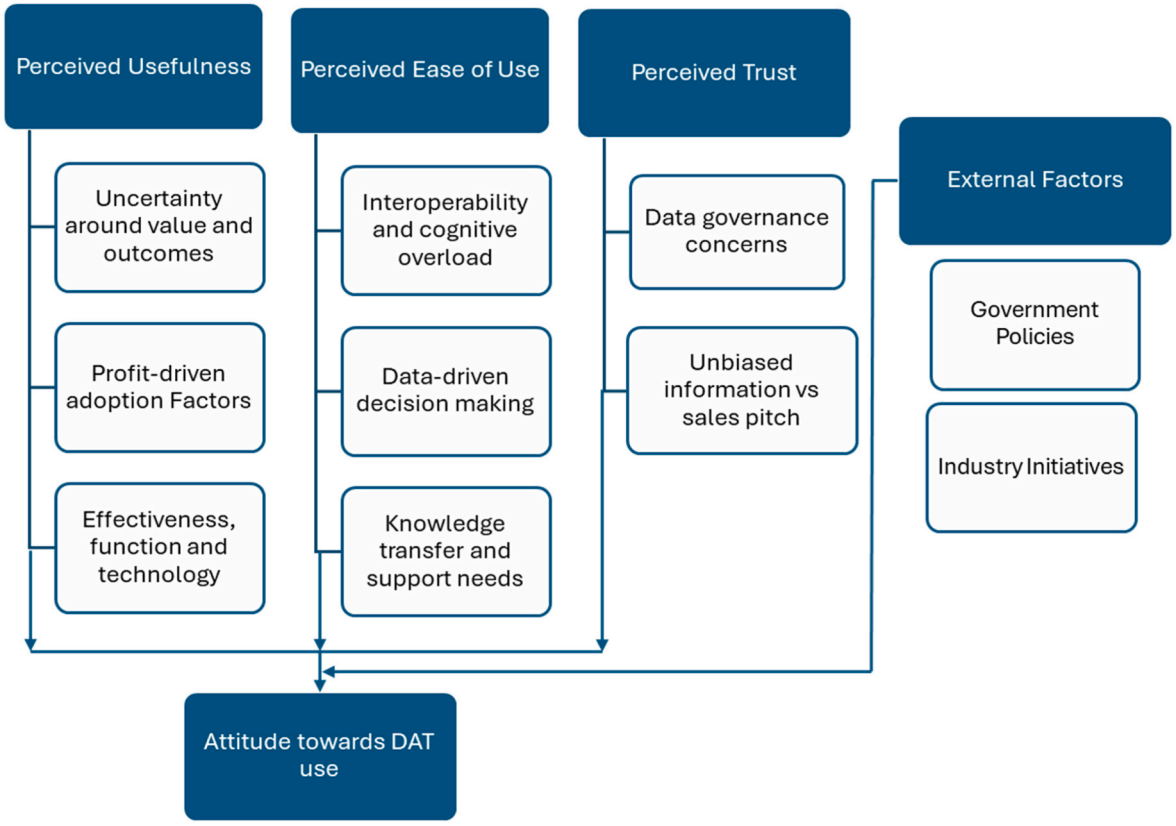

Fig. 2. Structure of the thematic analysis.

4.1.2. Effectiveness, function, and technology

To better understand how the functionality and effectiveness of DATs contribute to their perceived usefulness and adoption, we categorized the tools mentioned in interviews into five types. As presented in Fig. 3, precision agriculture and field analysis technologies emerged most frequently (n = 27), followed by livestock and collaborative solutions (n = 7), finance, farm operations, and equipment management (n = 6), and market and risk management tools (n = 4).

Precision agriculture tools, particularly those used for soil and yield mapping to inform variable rate application prescriptions, were the most functionally integrated across operations. However, the perceived effectiveness of these technologies varied sharply between service providers and producers. While service providers expressed confidence in VRT's value—often citing widespread client adoption and data-driven

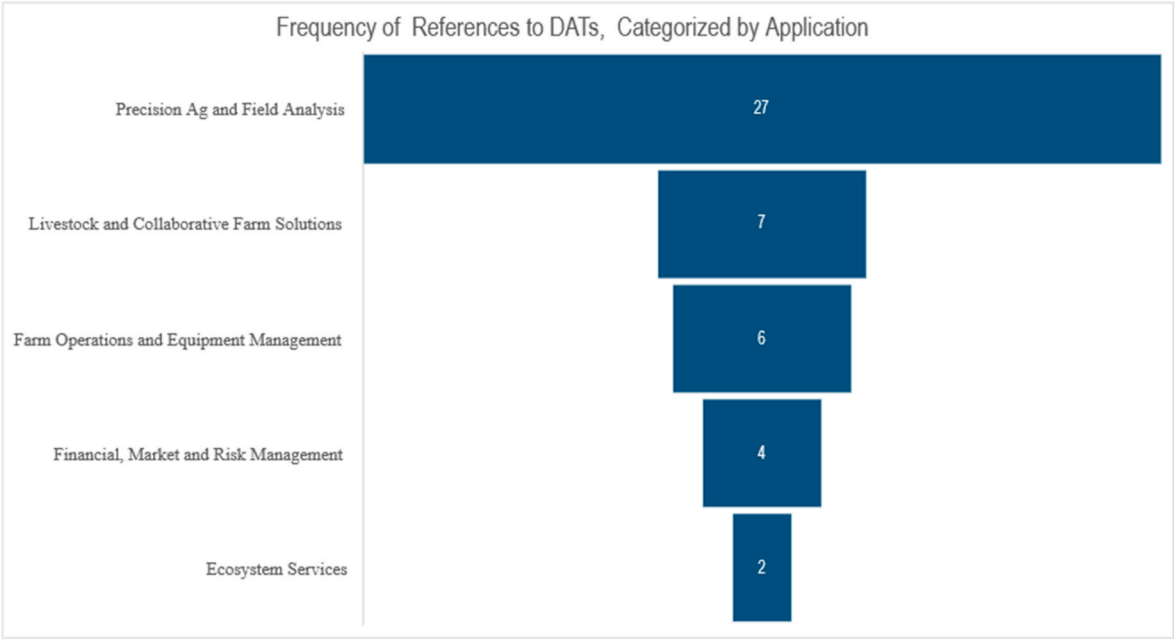

Fig. 3. Respondents' references to DATs by application.

results—most producers, with one exception (an agronomist), reported underwhelming outcomes. One large-scale crop farmer (17,500 acres) characterized their experience with VRT as a *"trial-and-error journey"* and stated, "*it hasn't really worked that well for us."* Despite this, the same producer continues to integrate a highly digitized suite of tools including GPS, yield monitors, SMS analytics, and financial systems such as Farm Maximizer and AgExpert. The continued use of these tools suggests that while individual DATs like VRT may fall short, the broader ecosystem of integrated technologies still contributes to operational decision-making and, by extension, perceived usefulness.

A service provider contextualized these mixed results by highlighting a temporal gap in producers' understanding of their land. He argued that while traditional land knowledge can take years to develop, *"with DATs, the data could give them this information in six months,"* framing the value proposition not as immediate profitability, but as accelerated learning and improved confidence in long-term land management decisions.

Other producers offered examples of DATs that provided clearer functional benefits. A grower in the Peace region, for instance, praised the practical value of satellite imagery for seasonal decision-making. While acknowledging its limitations (e.g., cloud cover and satellite pass timing), they emphasized that receiving up to 25 maps per season enhanced in-field scouting, fungicide application timing, and harvest planning. In this case, the effectiveness of the tool—frequent, actionable insights throughout the growing season—reinforced its perceived usefulness.

A mixed crop and livestock producer illustrated how technological integration across enterprises enhances utility. On the crop side, they employ GPS mapping, yield monitors, and grain bin sensors; on the livestock side, HerdTrax and a digital chute system are used for both bison and beef. Notably, simple technologies like calving cameras stood out: "*The ROI is in saving more animals,"* they explained, linking ease of use and tangible outcomes to high perceived value. Looking ahead, the producer expressed optimism for tools like virtual fencing and more precise enterprise-level cost tracking, anticipating better ROI analysis and decision support.

A producer and agronomist outlined a highly data-intensive and technologically advanced operation, using *"RTK guidance for sub-inch GPS accuracy, along with GreenSeeker NIR sensors for vegetation mapping and CropScan 3000H for measuring grain quality in real time"*. They build long-term productivity zones using NDVI and historical yield data to guide fertility prescriptions. Here, the effectiveness of these tools lies not just in standalone performance but in their ability to simplify complex operations, revealing how usability and system compatibility also shape perceived usefulness.

In contrast, a small-scale producer described limited engagement with DATs beyond basic GPS and spreadsheets, citing scale and return on investment as key barriers. However, they acknowledged that as technology becomes embedded in newer equipment, its use will become standard: *"Even for smaller operations like mine … I don't see this trend ever going backward."* This suggests that perceived usefulness is not static but evolves alongside operational scale and technological diffusion.

A researcher who is also a service provider echoed this scalability theme, explaining how remote sensing through multispectral imagery (Sentinel and Landsat) combined with crowdsourced yield data enables regional modeling across the Prairie Provinces. Though resolution is lower than UAV data, the trade-off is expansive coverage, reinforcing that effectiveness and usefulness are context-dependent—high granularity may be less valuable than broader applicability in certain use cases.

Some producers shared the negative experiences with some DATs. For example, a few respondents noted that Farmer's Edge, a digital agriculture solutions company, failed to meet expectations, which further undermined producers' confidence in the potential of DATs to live up to the hype. Other producers showed skepticism about the value of all the new technologies for their operations.

4.1.3. Profit-driven adoption factors

Perceived usefulness of DATs is also captured by one of the sub-themes on factors of adoption. The main factor, determining usefulness and in turn adoption, highlighted by all the producers was cost savings and increased profitability. One major value proposition for variable rate application of inputs is that it saves producers' money as data and analysis helps them use inputs more efficiently. Even if they are saving on fertilizer input, the reallocation across different zones increases yields and improves soil health. Other factors highlighted by one the producers who farms a relatively smaller piece of land (320 acres) was the size of the farm. If the cost is spread over bigger acres, it is easier to see the returns. For small farmers, even if they see the value, the high upfront cost is a limiting factor. An AgTech communicator viewed higher adoption by larger farms due to more time and head space because more people work for the producers, sparing them time to look for better technologies and make investment decisions.

An agronomist shared that the return on investment often lies not in reduced input costs but in benefits such as reducing lodging, which can significantly boost yield, improving harvestability by allowing for more consistent and efficient operations, and enhancing crop quality—particularly important for seed growers. These factors, while tied to cost, also reflect deeper, operational values that digital technologies can support by enabling more precise, localized field management. If the DATs are perceived to be reducing costs, improving yields, reducing lodging, and improving consistency of their produce, producers tend to adopt them fast. These factors play a key role in determining the usefulness of DATs for the users which is an important determinant in their decision to adopt these. There are other factors such as demographic, peer networks and technical support but those are discussed under the other components of the TAM.

4.2. Perceived ease-of-use

This theme emphasizes the user-friendliness of DATs. Within this category, three key sub-themes were identified: Interoperability and cognitive overload; Data-driven decision-making; and Knowledge transfer and support needs.

4.2.1. Interoperability and cognitive overload

Interoperability between digital agriculture technologies remains a central challenge for producers adopting precision tools across mixed fleets and platforms. Respondents frequently described the fragmented nature of digital ecosystems, where equipment and software from different manufacturers often fail to communicate effectively. As one participant noted, "A Case monitor doesn't talk to a John Deere tractor, for example … That's where SMS is nice because it talks to everything." Others echoed similar frustrations, indicating that despite the promise of integration, many systems remain siloed—requiring multiple software packages to analyze, transfer, or even view data.

Farmers often find themselves having to learn and maintain proficiency in multiple systems, each with their own interfaces and data formats. As one participant analogized, "It's similar to what you see with an Android phone versus an Apple phone … you either go in one lane or the other, and it's harder to bridge." These limitations become especially burdensome when compounded by time constraints and the need for ongoing training, as another shared: "Instead of going to one training session … they have to go to two or three … that is prohibitive."

Even those committed to cross-platform data usage find the process demanding. Several respondents mentioned having to input the same data multiple times across separate systems, calling it "frustrating and time-consuming," and a form of "mindless work." The reliance on third-party or costly integrator software further raises the technical and financial threshold for entry, reducing accessibility for smaller or diversified operations. The lack of standardization across systems adds layers of inefficiency and makes it more difficult for farmers to adopt new technologies confidently. Despite emerging tools and middleware

solutions, they often require advanced technical skills or costly licenses, making them inaccessible for many producers. Consequently, farmers may feel locked into a single brand or hesitant to invest deeply in any platform, limiting both adoption and innovation.

Furthermore, the North American implementation of interoperability standards such as ISO has been criticized as incomplete or misleading. One agronomist explained: "North American ISO is not the same [as European ISO] … you plug it in, and the monitor can see the drill. However, I can't do variable rate … the systems have built-in limitations … and it doesn't work seamlessly."

Despite these challenges, some producers acknowledged gradual progress in improving system integration. Manufacturers such as John Deere, Case, and Climate FieldView have expanded their use of ISOBUS and API-based architectures, allowing for easier data import and fleet tracking. As one participant noted: "You can plug into the ISOBUS or CAN bus … and transmit data from different brands of equipment … it is getting easier." Moreover, those using shape file–based data frameworks or third-party GIS tools like ArcGIS reported greater flexibility: "As long as you are creating shape files, there is no issue … You have access to every manufacturer's equipment." While there are emerging solutions and some signs of standardization, most respondents continue to experience this as a persistent and practical barrier to widespread, seamless DAT adoption.

4.2.2. Data-driven decision making

Another recurring theme among participants was the disconnect between data collection and its effective use in decision-making, reflecting a critical constraint on the perceived ease of use of DATs. Although the capacity to collect large volumes of data through equipment and sensors is widely acknowledged and increasingly adopted, respondents frequently noted that translating this data into actionable insights remains a key bottleneck.

Several interviewees articulated that while producers readily adopt data-generating tools, they often struggle to implement the data in meaningful ways. One agronomist described this trend: "The adoption of new technology, like an app on your phone, can be very high, but when it comes to making decisions like applying different fertilizer rates per field … adoption drops significantly."

This illustrates a gap between surface-level engagement with technology and the deeper cognitive and operational work required for data-informed management. Many producers collect data routinely but are either unsure how to interpret it or lack confidence in making changes based on the analysis. As one service provider mentioned the confusion of the producers: "You can look at all the information … but what do you change, or what do you adjust, or what do you improve on, now that you know the information?"

Another concern among users of DATs, cited by most of the respondents, was the gap between data insights and actionable outcomes, which contributes to hesitancy around long-term technology adoption. One producer emphasized the need for systems that not only analyze agronomic variables such as nutrient levels but also generate a clear set of viable, context-specific solutions: *"The magic sauce is turning insights into action. It's not enough to know you have low zinc—we need systems that go the next step and say, 'Here's exactly what to do.' That's what makes data truly valuable."*

Without this *"bridge"* between insight and action, producers are left without the necessary support to leverage the full potential of digital agriculture technologies, thereby diminishing perceived usefulness over time. These sentiments were reinforced by others who emphasized that data interpretation often requires additional knowledge or third-party expertise. One producer stated, "*The use rate is increasing, but the amount of time that growers would sit down and do data analysis is probably not as high as it could be.*" Another reflected on the psychological barrier: "*There is still a disconnect … producers don't even believe in the data … not that they think the data is overpriced, they just don't believe in it.*"

This skepticism or uncertainty is compounded by the complexity of agronomic interpretation. One agronomist explained, *"Understanding it—like, what does your parts* per *million of potassium actually have to do with yield potential?"*—is not a straightforward task, and even mentors in the field may lack clarity on such nuanced relationships.

Technical limitations can also hamper data usability. Proprietary formats and reduced-resolution maps restrict how data can be integrated across platforms. For example, one agronomist noted that "*their high-resolution SWAT maps are less compatible with other low-resolution maps of the other systems"*. Despite these constraints, some respondents provided examples of effective data use in guiding production decisions. For instance, one service provider described how zone maps based on historical NDVI, and yield data are used to generate fertility prescriptions for 30–40 % of their clients, demonstrating how layered data inputs can drive variable-rate applications. Still, these examples represent exceptions rather than the norm, often enabled by strong external support systems or advanced user familiarity.

Another critical constraint on the *perceived ease of use* of digital agriculture technologies relates to data quality and the user's role in its generation, revealing a deeper tension between technological capability and farmer engagement. Multiple respondents emphasized that while equipment can collect robust data, much of it is rendered unusable due to poor input standards or inconsistent execution. As one expert noted, *"less than 20 % of the time, other service providers collect data in a form that can be used."* Another echoed this by describing an internal pilot with 60 growers, where only 10 % of the yield data was useable. This low utility rate highlights the enduring 'garbage in, garbage out' problem, where inaccurate or improperly entered data severely limits downstream value. The complexity of data collection, interoperability and use coupled with limited time and head space, has led most farmers to take a hands-off approach, either by necessity or preference. As several agronomists echoed, farmers *"don't want to be bothered,"* "*lack the time during critical seasons*", and are often *"not great at it,"* not because they're incapable, but because it's not their area of expertise or interest.

4.2.3. Knowledge transfer and support needs

Perceived ease of use is significantly compromised by poor interoperability, requiring producers to either stay within a single brand ecosystem or invest time, money, and expertise to bridge incompatible systems. Such workarounds often require technical expertise that is not uniformly available on-farm. At the same time, retention of skilled support personnel is a persistent issue. Respondents shared examples of excellent technologists, often recent graduates from ag-tech programs, who quickly advanced out of the field or moved away. The loss of key staff with specialized knowledge, as one respondent recounted, left a "*gap that the OEM's service* support *could not readily fill"*.

Effective adoption and long-term integration of digital agriculture technologies hinge significantly on knowledge transfer and support services. Across interviews, a consistent theme emerged: while farmers are keen to learn and often quick to pick up new technologies once shown, the formal avenues for training and support are often insufficient or unevenly distributed.

Several interviewees described a tiered support experience, where larger operations or those purchasing significant amounts of equipment receive more individualized attention from dealers and service providers. Smaller farms, by contrast, may struggle to access the same level of expertise, leading to inequities in digital adoption. As one participant noted, "if you're a big farm that comes in and spends a lot of money on equipment every year, you're going to get top notch service … If you're someone that goes in there and replaces something every 8–10 years, you're not going to get that same knowledge transfer."

To fill this gap some companies, offer full-service models that minimize the need for farmer involvement in technical setup and data collection, many producers still prefer or are required to manage aspects of the process themselves. As one service provider observed, "there are very few farmers that are going to map their own fields … they'd rather hire you to do it."

For many producers, this was not simply a matter of technical complexity, but a broader issue involving understanding, education, and cognitive load. Even when technologies were recognized as valuable, the steep learning curve often acted as a deterrent. As one participant noted, "There's also an understanding and education barrier. This stuff is complicated, and that's another hurdle to overcome."

Much of this challenge stems from a historical gap in formal education. Several producers pointed out that precision agriculture had only recently been incorporated into post-secondary curricula. Until very recently, most learning about DATs occurred on the job or through sales-driven interactions. "The education system has been a decade behind," one respondent observed. "How do we expect anyone to know about it when the only people that know about it are the ones selling it?"

Even when information was technically available—through manuals, online resources, or peer-to-peer platforms—it was often described as disjointed, difficult to interpret, or buried under layers of technical jargon. "The information exists," said one industry stakeholder, "but it needs to be more accessible and easier to find." This points not to a lack of data or guidance, but a failure in usability and communication design. Time, attention, and mental bandwidth also emerged as limited resources on many farms. As one participant succinctly put it, "Adoption is low, and I think a lot of that comes down to knowledge, information, time, and headspace." Service providers also recognized this barrier. They emphasized the value of face-to-face interaction, particularly in settings like trade shows where producers can ask questions and see technologies demonstrated in real time. "They want to talk. They want to build that knowledge base," one said. "It's a whole different game when you're at a trade show and can ask questions."

Despite these challenges, there is optimism. Many producers view the learning curve as surmountable, and several emphasized that "*even older generations adapt quickly once they are shown the ropes*". The key barrier, therefore, is not a lack of interest or capacity, but the availability and consistency of knowledgeable, on-the-ground support.

One of the participants highlighted the role played by the federal and provincial governments in technology development and extension. "We need more programs, and a centralized extension agency—provincially, at least—to validate and demonstrate new practices on-farm. More funding is needed to de-risk technology trials for farmers, so they can see ROI before committing." However, over time, with a lot of new technology coming out, governments became cautious, and those investments have declined. Technology manufacturers have taken that space, but some participants highlighted their "bias" and emphasized the need for unbiased information to producers. A policy advisor on agriculture digitization observed that, "Governments are recognizing the need to take risks. Part of this is rebuilding immersive extension frameworks so farmers of all ages and backgrounds have repeated opportunities to learn about technologies."

4.3. Perceived trust

4.3.1. Data governance concerns

Concerns about how farm data is governed (particularly in relation to ownership, control, and ethical use) emerged as a complex, often contradictory dimension shaping farmers' trust in digital agriculture technologies. While some respondents expressed indifference toward the issue, others raised nuanced criticisms of the existing industry frameworks and certifications meant to promote transparency.

A recurring sentiment among more experienced industry professionals was that farmers tend to overestimate the proprietary value of their individual farm data. One respondent noted, *"One farm's data isn't worth much. It's when you aggregate enough data that it becomes useful for decision-making."* Despite this, they also acknowledged how perceptions of data misuse—especially when companies are seen as profiting from farm-level information without clear value-sharing mechanisms—can become a flashpoint for mistrust. *"People freaked out … but if you can show me a company making huge money from farm data, I'd be surprised"*, as noted by a large farm owner and crop producer.

Other participants, particularly those representing service providers, emphasized that the core relationship with producers is service-oriented, not data-driven. As one precision ag provider explained, *"They're buying a service from us, not buying data … The only time the data conversation comes up is if someone's leaving."* Still, proprietary mapping and data systems were described as tightly controlled, with limited portability: *"There's a lot of data in our system they can't access … it can't be reassigned to someone else"* noted one tech service provider.

For some, data governance concerns were inseparable from broader frustrations about power imbalances and closed-door industry arrangements: "This isn't about data anymore … everything's blocked by business arrangements, sponsors, and side deals." At the same time, others reported little concern about how their data is handled, particularly when working with trusted firms. A former Monsanto employee reflected, "Companies like John Deere and Climate FieldView are very committed to not misusing data … I don't have any concerns." Similarly, for many growers, data security and ownership remain low-priority issues unless abuse becomes visible or results in lost value: "It's probably a good thing to say your data is secure, but I don't think it's a huge issue."

Despite that there is growing awareness, especially among newer entrants and younger producers, that data governance may become more consequential as the industry matures. One agronomist highlighted the shifting tone: "Fifteen years ago, people didn't care where their data went. That's changing—especially with AI and new platforms." Another emphasized that, from a producer's standpoint, "Why should I give you all my data and then you make the money off it? There needs to be value all along the chain."

Overall, while data governance concerns do not currently constitute a universal barrier to technology adoption, they represent a latent trust issue—one that may intensify as digital platforms evolve and as producers become more conscious of the long-term implications of data-sharing agreements.

4.3.2. Unbiased information vs sales pitch

Peer-to-peer influence was identified as a powerful driver of technology diffusion among farmers. One service provider described how informal networks and referral programs significantly contribute to their customer base. Farmers often share experiences with neighbors or peers, prompting others to reach out for more information or adopt similar technologies. As one participant noted, *"they are their own entities, but they like to really look over the fence, so to speak, all the time."* Certain individuals—described as *"mavens"*—play an especially active role in connecting others and encouraging adoption, acting as trusted sources of information within their communities. An analyst working for the Government of Alberta also confirmed this view.

Participants also called for more neutral, public knowledge infrastructure. Rather than learning about technology through brand-driven channels, producers expressed a desire for unbiased, brand-agnostic education about what DATs do and how they compare.

4.4. Attitude toward using DATs

Adoption of DATs is closely linked to farmers' attitude toward change, perceived risk, and generational dynamics. Many respondents highlighted that unless a technology clearly demonstrates tangible benefits, especially in time or cost savings, farmers are unlikely to adopt it. Even when such benefits are evident, psychological resistance and attachment to tradition often outweigh practical considerations. However, economic considerations are deeply entangled with cultural and psychological orientations. Several participants referenced generational divides, describing how *"older generations, which often resist change, are still in control of many farms."* The persistence of traditional practices was frequently linked to a strong desire for consistency in the face of narrow profit margins. *"If something has worked for 20 years*," one participant noted, *"they're hesitant to change."*

The diversity of technological adoption in agriculture is closely tied to demographic factors, personal motivation, and educational background. One participant highlighted how attitudes toward technology are not strictly age-dependent, noting that some older farmers are just as engaged with digital tools as younger ones. What truly makes a difference, they observed, is the *"desire to grow your knowledge"* and not being *"afraid of tech."* Education levels also vary widely—from individuals with minimal formal schooling to PhDs returning to manage farms, yet those most willing to engage with DATs are actively seeking out solutions, whether through local consultants or established service providers.

Some farmers, particularly those with deep generational ties to their land and farming practices, may rely more on intuition and experiential knowledge than on data. As one participant noted, *"a 50-year-old farmer working land homesteaded by their grandfather might still value numbers, but their decision-making tends to be more gut-based than data-driven."* This highlights how long-standing habits, and personal history can shape attitudes toward digital agriculture technologies.

This resistance to change was described not just as inertia, but as a protective mechanism against perceived risk. As one respondent observed, "Farmers have to be fairly risk-averse to maintain the farm for generations … If they take too many risks, they could lose it all." This risk aversion can manifest in skepticism towards innovation, where data or technological claims are dismissed out of hand. In one case, a grower remarked, "You can show me all the numbers, but I'm still going to do the same thing as I've always done."

Some participants recounted instances where producers tried DATs with the expectation—or even the hope—that they would fail, reinforcing an existing bias against adoption. Others described a kind of behavioral inertia, where the cost of change was perceived not in financial terms but as "the discomfort of making a change." This unease was further reinforced by ideological beliefs about tradition and self-sufficiency, exemplified by the statement: "My family has always done it this way … we don't need any of this technology to do it."

Even when variability in field performance was demonstrable, farmers often failed to connect it to actionable decisions. One respondent highlighted the contradiction, noting that although producers may acknowledge yield variation across a field, they may still assert, *"I don't have variability,"* using this as justification for not exploring variable-rate technologies.

4.5. External factors

Some external factors also play a role in shaping adoption dynamics indirectly by addressing concerns related to perceived usefulness, ease of use and trust in DATs and attitude of the end-user towards them. We asked the participants questions about the role of government policy and industry led initiatives in improving the adoption of DATs. We asked specifically about the 'Ag Data Transparent' initiative that provides certification to ag tech providers if they meet their criteria to ensure transparency in using, storing and transferring farmers' ag data. Perspectives on these influences reveal divergent views among producers, agronomists, and industry professionals, with skepticism, frustration, and cautious optimism forming the core of these attitudes.

Several producers expressed deep skepticism toward government intervention in agriculture. One farmer remarked, *"the government should stay as far away as possible from trying to help agriculture,"* citing a fundamental disconnect between policymakers and on-farm realities. Others echoed this view, stating that government mandates may artificially push technology adoption, which some view as contrary to the ethos of self-determined decision-making.

Despite these sentiments, there's a recognition that government programs can drive change, albeit imperfectly. For instance, a producer who attended the Agro-Technica show in Germany noted that policy mandates around chemical use were instrumental in driving adoption of spot-spray technologies—an example of how regulation paired with incentive can foster innovation.

Several respondents noted that while programs like OFCAF and SCAP[3] provide useful financial support, they are administratively complex. Producers expressed fatigue over the burden of paperwork, auditing, and verification. As one put it, *"keep it administratively simple … it's the accountability piece that creates the complications."* Others questioned whether the costs of administering such programs outweigh their benefits. This points to a key trade-off: while public funding requires accountability, excessive complexity may discourage participation—especially from smaller or time-constrained operations.

Opinions on industry-led data transparency initiatives—particularly the Ag Data Transparent (ADT) seal—were mixed among participants, reflecting broader tensions between formal certification efforts and producers' lived experiences with data governance. While some respondents viewed the ADT framework as a step in the right direction toward building trust and establishing standards, others questioned its practical value, ethical scope, and impact on everyday decision-making.

For some industry participants, the ADT seal represents an important structural guideline that could help differentiate reputable providers from opportunistic actors, particularly in an increasingly crowded digital agriculture market. They suggested that such certification may help pressure companies to adopt more responsible data handling practices and potentially give producers greater clarity over how their data is used.

However, skepticism was also prominent. Several participants criticized ADT and similar programs as superficial or symbolic, noting that transparency alone does not guarantee ethical data use. Some voiced concern that companies could technically follow transparency standards while still engaging in practices that benefit corporate interests over farmer rights. One farmer-entrepreneur argued, *"I can transparently say I'll do whatever I want with your data and resell it … that's transparency, but not ethics."* Additionally, there were doubts about whether farmers themselves find certifications meaningful when choosing technologies, with some arguing that such seals do not influence producer trust or adoption behavior.

5. Discussion

This study explored the adoption of DATs in Alberta's crop and cattle operations using the TAM as a guiding framework. Drawing from interviews with producers, AgTech service providers, and other stakeholders, we uncovered a complex landscape marked by gaps in innovation-readiness, data governance concerns, and policy support. It became apparent that producers would only adopt DATs if they believed that their benefits outweigh the costs. The benefits could be direct or indirect. For example, the benefits of improvement in soil health due to precision agriculture accrue in the medium to long run and it would depend on the discounting how much the producers value them today. External factors like precipitation rates in dryland farming always come into play and make the assessment of DATs difficult from one year to the other. Farming in Alberta is largely a generational business and making a change in farming and business operations depends on the perception about the usefulness of change over multiple generations.

While the results provided rich empirical insights into these themes, the discussion below offers a forward-looking synthesis that identifies systemic challenges and proposes conceptual avenues for closing the adoption gap.

[3] OFCAF: On-Farm Climate Action Fund, a federal cost-share program supporting on-farm practices to reduce emissions.SCAP: Sustainable Canadian Agricultural Partnership, a federal–provincial–territorial framework for agricultural funding and policy.

5.1. Addressing the innovation-readiness gap

A key divergence emerged between the pace and complexity of innovation driven by AgTech developers and the readiness of producers to adopt such technologies. Many new tools fall short of this standard because they lack the contextual relevance or integration required to turn insights into actionable strategies. From a policy perspective, organizations using technology readiness levels (TRLs) to gauge the development and prospective market value of the innovative product should base their assessments also on context of institutional readiness. Webster and Gardner (2019) provide an innovation adoption framework that embeds institutional readiness within a broader socio-technical framework. The integration of artificial intelligence (AI) offers a promising path forward by enabling more personalized, predictive, and prescriptive solutions from variable rate seeding to real-time animal health monitoring, but such tools must be designed with the end-user in mind. A participant working with a venture capital fund highlighted that, "*agriculture moves slower than other tech sectors due to seasonality and adoption timelines. We need patient, continued* funding *for accelerators, incubators, and smart farms.*"

While service providers emphasized the benefits and technical capabilities of DATs, producers often voiced skepticism about the actual value these tools offer in their day-to-day operations. As a result, producers feel underserved in translating data into decisions, frequently turning to agronomists or consultants to fill this gap. This mismatch is compounded by a service model dominated by equipment vendors that primarily focuses on machine operation rather than agronomic insight. The problem is not solely technical but also logistical and cognitive. This adds friction to the perceived ease of use, as producers may view data tools as time-consuming, unreliable, or requiring external expertise to fix, reducing their willingness to engage fully with digital systems.

The innovation readiness gap is not an Alberta specific challenge and the studies in various jurisdictions have highlighted solutions that could be applied across various agricultural contexts. For example, Hansen et al. (2023) find that agronomists in Australia usually have the trust of the agronomists and are well placed to help bridge the technology and end-user gap if supported by AgTech providers, government bodies and peer networks. The integration of decision support systems, powered by AI and validated through agronomic trials, could complement existing services and extend their value proposition. Such hybrid models would not only strengthen the usability of DATs but also address the service vacuum that currently alienates producers from digital innovation.

5.2. Building trust through better data governance

Trust emerged as a critical factor influencing technology adoption. Challenges regarding data governance and transparency are not specific to Alberta and persist across various jurisdiction contexts (Khannal et al., 2025). Producers frequently cited concerns over data ownership, transparency, and interoperability. While service providers generally expressed confidence in their data handling protocols, producers were less assured, particularly in situations involving vertically integrated platforms or multinational firms. This asymmetry in perception exacerbates mistrust and deters engagement with potentially beneficial technologies.

Producers need assurances that their data will not be monetized without consent or used in ways that disadvantage them. Data ownership concerns remain a significant, often hidden barrier to digital agriculture adoption. This issue is not unique to Alberta, and international literature has consistently advocated for open and transparent data governance frameworks to address it (See for example, Duncan, 2023; Fleming et al., 2018; Kosior, 2018; Wiseman et al., 2019; Wolfert et al., 2017; Zhang et al., 2017). Clear, enforceable data governance standards alongside transparent communication are essential to rebuilding this trust. Furthermore, co-designing data platforms with producers and integrating them into decision-making processes could shift the dynamic from transactional to collaborative. A trusted data ecosystem requires both regulation and relationship-building. Instead of using one model, a holistic approach to give the right mix of data rights such as access, sharing, or re-use depending on the sector's needs is needed to be developed with broader stakeholder participation as proposed in the EU Data Act (Atik, 2022).

5.3. Reframing support systems and communication strategies

Many producers, especially those from older generations or in multi-generational operations, view innovation through the lens of past success, valuing consistency over experimentation. In these contexts, reluctance is not necessarily a rejection of technology but a defense of proven systems under uncertain conditions. While many acknowledged that digital tools and platforms often produce high-quality data, the challenge lies in integrating these outputs meaningfully into farm decision-making systems. This fragmentation contributes to a sense of disconnection between digital agriculture as a concept and its practical application on the farm. It often results in early enthusiasm followed by tapering adoption, as users struggle to translate raw data into tangible improvements or economic returns.

Many producers rely on informal support systems to bridge the knowledge gap. Sales representatives and social media groups often become de facto educators, with farmers teaching themselves through trial, peer exchange, and online discussion forums. While this grassroots model provides real-time, practical solutions, it lacks consistency and may not always provide the depth or technical rigor required for more complex tools like variable rate applications or integrated data platforms. The current model of knowledge transfer anchored in demonstrations and technical support for hardware does not adequately address the cognitive and interpretive needs of producers. Farmers interviewed expressed the need for unbiased, practical communication that helps them understand how marginal improvements in their practices can yield high returns. Peer-to-peer learning, independent advisory services, and integrative field trials emerged as key enablers in bridging this gap. The importance of diverse communication channels, particularly interpersonal events such as Ag Days, has also been highlighted in recent research by Colussi et al. (2024).

Addressing these barriers to adoption requires more than demonstrating a return on investment; it calls for reframing the narrative around change itself. This may include positioning DATs not as disruptions, but as tools that extend existing knowledge, safeguard profitability, and sustain legacy farming systems. More critically, there is a need to reimagine service delivery models. While equipment providers play a vital role in enabling the use of machinery, their focus rarely extends to guiding data-driven agronomic decision-making. Going forward, coordinated efforts between manufacturers, educational institutions, and ag-tech providers could help close this gap and support more equitable and confident adoption across farm sizes and types.

5.4. Toward a multi-Dimensional framework for adoption

Addressing DAT adoption challenges in Alberta agriculture requires a holistic approach that spans technical, social, and institutional dimensions. Based on this study, we propose a conceptual framework comprising four key pillars.

- Technological Fit and Functionality: Tools must align with farm-level realities and seamlessly integrate with existing workflows.
- Trust and Transparency: Data governance practices must be transparent and equitable to build producer confidence.
- Capacity and Communication: Support systems should go beyond functionality to include interpretation and agronomic application.
- Policy and Market Alignment: Incentive programs and public investments must reflect both the early adopters and the broader community, addressing equity and effectiveness.

Together, these dimensions form a roadmap to guide policy makers, developers, and extension agents in creating a more inclusive and effective digital agriculture ecosystem. Future work should continue to build on these findings by developing regionalized solutions and evaluating the effectiveness of emerging interventions, particularly those involving AI-based advisory tools.

6. Conclusion and policy recommendations

This study examined the determinants of DAT adoption in Alberta through the framework of the Technology Acceptance Model. The findings underscore that adoption is not solely contingent on financial considerations but is also shaped by interoperability, training, data governance, and the design of policy supports. Importantly, adoption is embedded within social contexts of trust, knowledge exchange, and institutional alignment, highlighting the limits of viewing technological uptake as a purely economic decision. Rather, adoption emerges as a socio-technical process in which producers evaluate not only the efficiency of tools but also the credibility of governance structures and the availability of meaningful support.

The analysis suggests that increasing adoption requires an integrated approach that couples technical innovation with institutional reform. Transparent and enforceable data governance, effective collaboration between producers, industry, and academia, and robust mechanisms for knowledge transfer are as essential as financial incentives. Furthermore, regionally relevant resources such as locally calibrated soil health data and demonstration projects that foreground farmer experiences play a critical role in bridging the gap between technological potential and practical application. Collectively, these findings contribute to a more nuanced understanding of the innovation-readiness gap and provide a foundation for future research and policy efforts aimed at fostering equitable and sustainable technology integration in agriculture.

CRediT authorship contribution statement

Hanan Ishaque: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Juhi Huda:** Writing – review & editing, Validation. **Guillaume Lhermie:** Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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Data availability

Data will be made available on request.

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