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From fields to markets: Diversification case studies in the U.S. Corn Belt via a social-ecological systems lens

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Abstract

Agricultural diversification is increasingly recognized as a systems-level strategy that enhances sustainability, resilience, and adaptability of agricultural and food systems under global environmental and market pressures. This research delves into the dynamics, opportunities, challenges, and key success drivers associated with agricultural diversification in the U.S. Midwest—a region historically dominated by corn–soybean rotations—through the lens of the social-ecological systems (SES) framework. Focusing on the integration of oats, wheat, and peas into existing systems, we employed a case study methodology combining theoretical, empirical, and contextual inquiry. Data collection integrates primary and secondary sources, including semi-structured interviews and participation in field days, spanning October 2022 to February 2024. Interviews with 29 actors, including farmers,

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industry representatives, and members of agricultural cooperatives and nonprofits, provided insights into market opportunities for diversified agriculture systems. The findings highlight that diversification outcomes are co-shaped by ecological interactions, market dynamics, policy environments, and collaborative networks. The cross-case analysis demonstrates that farmer decision making, knowledge co-production, supply chain coordination, and farmer–Extension collaborations are central mechanisms that foster ecological resilience, expand market access, and stimulate innovation. Through the SES framework, this research provides a novel synthesis that advances understanding of agricultural diversification as a system-level transition pathway. Beyond the Midwestern U.S. context, this research contributes to the body of knowledge on how agricultural diversification is a system-level transformation process and to broader debates on agroecology, sustainability transitions, and food system resilience, offering insights to guide future research, policy, and practice.

Keywords
market diversification, case studies, sustainability transitions, resilience, value-chain collaborations, social-ecological systems framework

Introduction
The global dominance of monocultures in agriculture has led to significant economic, ecological, social, and environmental vulnerabilities, including susceptibility to pests, diseases, and market fluctuations (Savary et al., 2019; Zhao et al., 2020). In the U.S., the Midwest Corn Belt is renowned for its high crop productivity, predominantly focused on corn and soybeans (Hart, 1986; Kim & Moschini, 2018), which play a significant role in global agricultural systems through their use in animal feed, biofuels, and food products (Farida & Singagerda, 2021; Tanaka et al., 2023). Yet, the specialization of Corn Belt systems raises concerns about long-term sustainability, climate resilience, and the provision of ecosystem services. Agricultural diversification has emerged as a crucial pathway for transitioning dominant monoculture production models toward more sustainable, resilient, and agroecological food systems. Evidence suggests that agricultural diversification is a necessary strategy for enhancing resilience and sustainability in worldwide agricultural systems (Han, 2021; Meraner et al., 2018; Prokopy et al., 2020; Roesch-McNally et al., 2018; Shirriff et al., 2022). From the social-ecological systems perspective, diversification is not merely a farm-level choice, but a systems-level adaptation that involves

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Ethics Approval and Consent to Participate
This study was approved by the Purdue University Institutional Review Board under IRB-2022-151, and informed consent was acquired from all study participants.

Author Contributions
KP: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing, Figures, Tables. BR: Conceptualization, Formal analysis, Writing – review & editing, Tables. AT: Conceptualization, Methodology, Writing – review & editing. LE: Conceptualization, Data curation, Formal analysis, Writing – review & editing. LP: Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing, Funding Acquisition, Project administration.

Consent for Publication
All authors have read and approved the final version of this manuscript and consent to its submission. Participants consented to the use of their interview responses and related materials for publication.

Availability of Data and Material
The data supporting this study consists of qualitative materials (interview transcripts) that contain identifiable information. Due to ethical considerations, data is not publicly available. However, de-identified excerpts may be provided by the corresponding author upon reasonable request.

Code Availability
Qualitative data were analyzed using NVivo (version 14), as described in the paper.

adapting markets, policies, knowledge networks, and supply chains.

This study examines opportunities and barriers for integrating oats, peas, and wheat into U.S. Midwestern agricultural systems. These crops support agroecological transitions, soil health, diet diversity, and market expansion. We define diversification as adding crops beyond corn-soybean rotations to boost resilience, economic stability, and environmental benefits. While diversification forms include intercropping, agroforestry, and polycultures, we focus on rotational diversification (Baldwin-Kordick et al., 2022; Hathaway, 2016).

Benefits of Introducing Additional Crops

Corn–soybean specialization in the U.S. has reduced crop diversity (Crossley et al., 2021), heightening economic, social, and environmental vulnerabilities (Prokopy et al., 2020). The intensification of these practices has contributed to environmental degradation and compromised the food system's ability to withstand shocks, indicating a pressing need for more resilient and sustainable approaches (Crossley et al., 2021; Prokopy et al., 2020). Diversified rotations can improve soil health, reduce chemical inputs, and increase the adaptability to changing conditions (Baldwin-Kordick et al., 2022; Hathaway, 2016). They also open niche and value-added markets that strengthen farm income and long-term economic stability (Torres et al., 2021). Beyond farm-level benefits, diversification supports risk management, fosters local food systems, and enhances community resilience (Traldi et al., 2024). By buffering against market fluctuations (Barbieri & Mahoney, 2009), diversified agriculture represents a pathway toward sustainable transformation in the U.S. Corn Belt.

Determinants of Crop Diversification

Understanding the multi-scalar drivers of crop diversification is critical for enabling system-level transitions toward sustainable agriculture. Market dynamics shape opportunities for farmers to diversify, particularly through seasonal or niche markets (Bellon et al., 2016; Torres et al., 2021). Reliable markets help buffer price fluctuations, enhance income stability, and strengthen rural resilience (Dube, 2016; Liebman & Schulte, 2015; Wan et al., 2016). Access to infrastructure and proximity to markets strongly influence diversification, while landholding size influences flexibility in introducing new crops (Kannan & Pohit, 2021; Rahman, 2009; Sichoongwe et al., 2014). Commodity interdependencies also affect diversification strategies. In the U.S. Corn Belt, prices of corn and soybeans are closely linked; when markets favor these dominant crops, farmers often prioritize short-term profits over diversification. Conversely, market volatility or declining returns can incentivize diversification as a risk-reduction strategy (Shirriff et al., 2022; Yuan et al., 2020). Other economic factors such as technological advancements, input costs, and infrastructure connectivity are also vital for crop diversification (Lancaster & Torres, 2019; Walo, 2016). Social factors, including norms, networks, and consumer preferences, are also correlated with agricultural diversifications (Ali, 2015; Cecchini et al., 2018; Traldi et al., 2024). Regulatory and incentivizing agricultural policies (i.e., features of governance) significantly impact land use decisions and conservation practices (Diffenbaugh et al., 2012; Lark et al., 2015).

In the U.S. Corn Belt, networks of farmers, marketing arrangements, and improved soil health provide important opportunities for diversification (Traldi et al., 2024). Nonetheless, higher farm revenues are linked to a decreased likelihood of adopting extended rotations (Roesch-McNally et al., 2018). Key barriers include limited markets for alternative crops, high land costs, difficult access to land, labor, and technical support, and the comparative difficulty and time required to diversify (Roesch-McNally et al., 2018; Traldi et al., 2024).

While challenges exist, collaboration among stakeholders is vital to an enabling environment for diversification (Forrest & Wiek, 2021; Hergesheimer & Wittman, 2012; Hills et al., 2013). Collectively, these dimensions—market, economic, social, and governance—are essential for understanding and optimizing markets for agricultural diversification. Farmers' decision-making processes further illustrate the multi-dimensional nature of diversification. Beliefs, perceptions of market access, and risk considerations affect adoption (Arbuckle et al., 2013; Prokopy et al., 2019; Robert et al., 2016; Torres et al., 2017; Torres & Marshall, 2018).

When farmers perceive markets as reliable and profitable, they are more likely to integrate alternative crops and practices (Arbuckle et al., 2013).

Despite growing recognition of diversification benefits, little is known about agricultural transitions to greater crop diversity or new market emergence/stabilization for alternative crops. This paper examines synergies among actors in oats, peas, and wheat markets in the highly specialized Corn Belt. Using a multi-case qualitative approach, we analyze opportunities, challenges, and critical success factors in diversified crop markets. Drawing on 29 interviews and regional field-day observations, we aim to generate system-level insights.

This analysis is guided by the social-ecological systems (SES) framework, which conceptualizes agricultural markets as embedded within interdependent ecological, economic, and social subsystems (McGinnis & Ostrom, 2014; Ostrom, 2009). SES highlights dynamic interactions among resource systems, actors, governance structures, and markets in "action situations" involving decisions, negotiations, and knowledge exchange. In the context of supply chain studies, and contrary to traditional analytical frameworks like the global value-chain approach, SES can help embed supply chains in the context of traditionally externalized and ignored factors, including ecological and social factors that both impact and are impacted by supply chains (Loomis et al., 2026). Applied to diversification, it reveals how collaborations among farmers, buyers, and support organizations shape market trajectories and system resilience (Schlüter et al., 2019). While recent work on diversification in the U.S. Corn Belt often broadly describes market and production challenges and opportunities (e.g., Roesch-McNally et al., 2018; Traldi et al., 2024), this paper more narrowly and deeply focuses on specific cases of successful markets to garner a richer understanding of the specific factors underpinning current and future diversification efforts. This paper examines three Corn Belt markets that illustrate diversification enablers and constraints. Across cases, we identify shared dynamics—agricultural management, market access, governance, and socio-environmental conditions—shaping market resilience and sustainability. The research advances understanding of diversification as system-level transformation and informs sustainable agricultural and food system transition pathways.

Materials and Methods

This research employs a multi-case design grounded in empirical and contextual inquiry (Denzin & Lincoln, 2005; Yin, 2017). Case studies explore specific contexts to gain deeper understandings of different processes, networks, programs, and other phenomena, such as supply chains, making this research approach appropriate for our exploratory study. The focus is on markets for agricultural diversification in the U.S. Midwest, specifically crops that could complement corn–soybean rotations. Using a most-similar systems approach (George & Bennett, 2005; King et al., 2021), three cases were selected—oats (*Avena sativa*), peas (*Pisum sativum*), and wheat (*Triticum spp.*)—to enable cross-case comparison and acquire broader insights into diversification dynamics.

The research addresses three objectives: (1) identify opportunities and challenges in diversified crop markets across markets, economic, social, and governance dimensions; (2) identify key success drivers for market growth; and (3) map challenges, opportunities, and drivers through an SES lens to understand local diversification enablers and constraints. Data came from semi-structured interviews and secondary data review (Baxter & Jack, 2008; Morse, 1991). For each case, units of analysis included actors involved in crop production and crop entry into the value chain: growers, primary and secondary processors, and supporting organizations along each crop's value chain; actors further along the value chain, including distribution, retail, and consumers, were excluded.

Purposeful Selection

Case studies were chosen collaboratively with the Diverse Corn Belt (DCB) project network (Diverse Corn Belt Project, 2022) via a systematic multistep process. A detailed matrix drawing on literature review categories (Table 1) was developed to inform key analytical dimensions considered relevant for understanding diversification processes, rather than to identify cases directly through a structured search protocol. Initial assessments used public information (websites, social

Table 1. Categories and Variables for the Purposeful Selection

Categories	Variables
Agricultural Management	Technical crop management, resource use, innovations for effectiveness and sustainability
Markets	Size, location, access for diverse crops; farmers' market engagement.
Economics	Profitability, risk management, scalability, returns
Social	Cultural aspects, actor relationships, networking for adoption success
Environmental	Sustainable practices' effects on resources, resilience, and market opportunities
Policy and Governance	Government, industry, nongovernmental organization (NGO) roles via policies, incentives, collaboration

media) to match variables. DCB input refined and confirmed selection for Midwest landscape representation. This multiple-case approach selected three cases of crops that fit within corn-soybean rotations and represent ongoing diversification efforts in the region for a comprehensive understanding of diversified markets (Yin, 2017): peas, wheat, and oats.

Employing a purposive case-selection strategy enables a comprehensive but varied dataset (Saunders et al., 2009) and ensures replicability for meaningful comparisons (Yin, 2017). We selected crops fitting corn-soybean rotations to identify factors influencing success, plus opportunities and challenges for actors. Findings reveal diversified agriculture dynamics, informing strategies for sustainable and resilient globally relevant farming systems.

Data Collection

This study incorporated primary and secondary data sources. Primary data were obtained through semi-structured interviews, approved by Purdue University's IRB (approval number: IRB-2022-151), with key actors actively involved with the selected crops. Secondary data, from publicly accessible sources—websites, podcasts, blogs, and social media—complemented these insights. Secondary data were collected from spring 2022 to spring 2024 and focused on materials relevant to the selected crops and their value chains in the U.S. Midwest, as well as broader information on global market trends and contextual developments shaping diversification.

Interviewees represented four groups: farmers, industry professionals (including processors), nonprofit representatives, and agricultural cooperative members. Participants were recruited via snowball sampling, starting with industry professionals and supplemented at field days to capture diverse perspectives while acknowledging potential biases (Heckathorn, 1997; Wilson, 2014), such as participants being connected within existing networks or actively engaged in industry events, which may limit representation of less-connected voices. The sample includes uneven representation across actor types, with a stronger emphasis on farmers and upstream actors, reflecting the study's focus on production and market-entry phases. While downstream actors were not included, this delimitation aligns with the research objectives and allows for deeper analysis of early-stage value-chain dynamics.

Data collection concluded when themes and insights consistently recurred. From October 2022 to February 2024, 29 of 53 contacted individuals were interviewed in person or via Zoom. All interviews were conducted by the same researcher to ensure methodological consistency. We conducted 29 interviews with diverse actors: 22 male, 7 female. Participants spanned Indiana (13.8%), Illinois (3.4%), Iowa (34.5%), and other states (Nebraska, Michigan, Minnesota, Ohio; 48.3%). Roles included farmers (44.8%), industry professionals (34.5%), cooperative members (13.8%), and nonprofits (6.9%); case studies spanned oats (44.8%), peas (24.1%), and wheat (31%). Table 2 summarizes characteristics.

We attended three Practical Farmers of Iowa (PFI) field days. PFI, a nonprofit promoting sustainable agriculture via farmer-led research, education, and community building, primarily serves Iowa farmers but influences beyond the state.

Table 2. Descriptive Information on Interviewees

	Male (*n* = 22)	Female (*n* = 7)
Role		
Farmer	13	0
Industry	5	5
Co-op	3	1
Nonprofit organization	1	1
Case Study		
Oats	11	2
Peas	5	2
Wheat	6	3

These events enabled engagement with farmers and actors producing the selected crops, aiding interview recruitment and the understanding of stakeholder dynamics.

Data Analysis

Interviews were audio-recorded and transcribed using Transcribe*Me*![1] Transcripts were analyzed via combined deductive-inductive coding: deductive codes from the literature review (as overarching categories) and inductive codes from the data (as subcategories). Table 3 summarizes the codebook (parent codes, subcodes, descriptions, examples). All subcodes appeared across the three case stud-

Table 3. Code Structure: Parent Codes, Subcodes, Descriptions Across Cases

Parent Code	Subcode	Description
Background	Role	Stakeholders (farmers, agribusinesses, NGOs, co-ops)
	Business profile	Type, experience, production, operations
	Type of diversification	DCB project classification
Agricultural Management	Effort to produce	Planning, labor, and resources for crops
	Knowledge	Expertise in production, harvest, and sale
	Adoption rate	Implementation of new practices and technologies
	Organic certification	Processes and standards
Markets	Required infrastructure	Facilities for production, processing, and distribution
	Access to markets	Ability to reach consumers or buyers
	Market stability	Supply, demand, and pricing
	Innovation	New ideas or technologies
	Quality of products	Excellence standards
	Quantity of products	Sales volume
	Marketability	Attractiveness and sales potential
	Consumer behavior	Patterns and preferences
Sociocultural	Motivations	Cultural drivers and values
	Stakeholder ties	Sector collaborations
	Networks	Relationship webs
	Prestige	Social recognition
	Product perception	Societal and market views
Governance	Government support	Policies and programs
	NGOs support	Nongovernmental organization, civil society, and private mechanisms
	Crop insurance	Financial risk protection
Environment	Environmental effects	Soil, water, and biodiversity impacts
	Sustainable practices	Environmentally responsible production and distribution
Economic	Risk	Uncertainties and management
	Future outlook	Trends and planning
	Scalability	Growth and replication potential

[1] https://www.transcribeme.com/

ies, confirming consistency and enabling thematic pattern identification.

The coding framework was refined via inter-coder reliability (Gardner, 1995; Sebastian, 2019). Two researchers independently conducted three rounds, discussing interpretations and reconciling until Cohen's kappa ≥ 0.7 (Cohen, 1960; Gardner, 1995). Round three reached kappa = 0.80; the principal researcher then coded remaining interviews independently using the finalized framework. The lead researcher applied this framework to remaining transcripts. NVivo14 supported data analysis, with separate examination of each case study to identify primary challenges, opportunities, and success factors.

A cross-case analysis synthesized findings across the three cases, guided by the SES framework, examining interactions among actors, governance systems, resource systems, and external socio-economic and/or ecological contexts. This approach offered theory-informed interpretation of commonalities and differences, highlighting multi-level interactions and feedback shaping decisions and outcomes in diversified agricultural value chains (Miles et al., 2013; Yin, 2017). The SES-grounded comparison provided a structured multi-case framework for understanding farmer behavior and complexity of system transformation.

A thematic approach was employed to explore relationships between cases, systematically identifying, analyzing, and reporting patterns or themes within the data about drivers of success (Braun & Clarke, 2019; Byrne, 2022; Vaismoradi et al., 2013). The cross-case analysis uncovered common themes and external-influence factors shared across cases (Braun & Clarke, 2021; Cheng & Catallo, 2023), which facilitated a deeper analysis of the interconnections between actors, scalability, and adoption rates, contributing to a comprehensive understanding of the drivers of success that influence agricultural diversification.

For objective three, two researchers mapped findings onto Ostrom's (2009) general SES model (resource systems or units, governance systems, actors and users, interactions and outcomes). This mapping revealed how interactions, and their absence, enable or constrain agricultural diversification pathways through value chains.

Results and Discussion

The results are presented in two sections. First, case studies highlight opportunities, challenges, and impacts for corporations and growers in oat, pea, and wheat value chains. These systems extend crop rotations by replacing corn or soybeans in one or more growing seasons, and they illustrate how different actors navigate diversification dynamics. Second, cross-case analysis maps resource systems and units, governance systems, actors, interactions, and outcomes as complex SES across social, ecological, and political contexts, showing how policy, ecological conditions, and social capital shape decision making for resilient, sustainable production and practical Midwest diversification implications.

Overview of the Case Studies

This section presents case studies of oat, pea, and wheat markets in the U.S. Corn Belt, highlighting opportunities, challenges, and success factors for diversification.

Peas

The pea value chain presents environmental, economic, and social benefits, while facing notable challenges and opportunities. With their nitrogen-fixing capability, peas enhance soil fertility by reducing reliance on external nitrogen inputs (Maharjan et al., 2019; Stevenson & van Kessel, 1996). A farmer explained that growing peas is like "growing their own fertilizer," reducing dependency on synthetic nitrogen fertilizers while supporting their rotation systems. While soybeans also fix nitrogen, participants noted that peas are typically integrated earlier in the rotation and can provide more immediate nitrogen contributions to subsequent crops, along with shorter growing seasons that allow greater flexibility in crop sequencing. Collectively, these factors contributed to overall soil health, supporting sustainable agricultural practices.

In terms of economics, interviewees shared that peas lowered input costs, improved crop yields, and increased profitability. The rising demand for plant-based products derived from peas (Stewart et al., 2020) is opening new revenue streams. A corporate interviewee commented:

> [Growing peas] was challenging at first because it's not something that [farmers] commonly used, and it was something that if they did use, it was for a cover crop, so they weren't cashing in on it. It was something that they would plant in order to help their yields or, forward-thinking farmers. So, when we came to market with peas and tried to encourage farmers to grow peas, they looked at us a little crazy. But we luckily had a market proven to buy it.

PURIS Foods, a processor that contracts farmers to produce peas, has leveraged the growing pea protein market for financial growth and sustainability goals. A U.S. leader in pea protein for plant-based foods, PURIS operates across grains, protein, and holdings (as described by a company member), focusing on food technology and product development in holdings (e.g., AcreMade brand). Actors noted that PURIS Foods' strategy met consumer demand via product innovation and strong partnerships with farmers and industry actors. For example, a corporate interviewees shared:

> There was a giant gap in the marketplace. No one could figure out the protein piece to work in coffee creamers or naked juices… (...) And we've been able to solve that …We've had huge interest from some of our partners in launching that.

Socially, interviewees noted peas in rotations improve food security and livelihoods via higher productivity and profitability. Reduced reliance on synthetic nitrogen contributes to improving community health and environmental quality. While peas are managed similarly to soybeans in many systems, participants noted key differences such as lower water requirements, offering potential water conservation benefits. These characteristics support resource-efficient production and contribute to the long-term sustainability of farming systems. A grain program staff member working with 500+ farmers stated:

> I think for us, it's to introduce a crop, in this case yellow field peas, to producers, not only to give them a market, which is important, and have it been successful on their farm, but I think the thing that gets lost in all of this is the sustainability piece to it. Because at the end of the day, all of the land that's currently farmed, the longer that we can farm it, the longer that we're going to be able to provide protein food, global food supply, all of those things…[peas] need a lot less water to prosper. Typically, soybeans are somewhere around 8–10 in of rain or irrigation per year, which is optimal. Peas can thrive on as low as 2 in of water per year.

A farmer noted how peas improve food security and livelihoods because they were easily introduced into existing crop rotation:

> Peas were a different type of crop that fit into a rotation that lets you plant peas, and then you could plant winter wheat after the peas that fall after you harvest them in July.

Despite these advantages, the pea value chain faces significant barriers. Corporations encountered farmers' skepticism about profitability and limited market demand, hindering scalability. Inadequate infrastructure and unpredictable yields further complicated expansion. Since few farmers grow peas, supply shortages and quality inconsistencies constrained companies' ability to market and sell pea-based products. As buyers noted:

> The most challenging part is just knowing how much—again, from our perspective as a buyer of peas, is not knowing how much we'll be able to grow, not knowing what the supply and, really, more importantly, the cost of that supply will be that year.

Producers faced persistent financial, technical, and logistical barriers to adopting diversified cropping systems. High transition costs, limited technical knowledge, and inadequate infrastructure remain key barriers to scaling pea cultivation. As some challenges persist, companies like PURIS indicated they are exploring international trials to meet growing demand. One member commented:

> We are exploring some other world areas like Latin Am, trying to grow peas down there and see if we can partner with some of those growing plant-based businesses across Latin America and then portions of Europe.

The expansion of plant-based protein markets presents significant opportunities for the pea industry. However, a growing reliance on international trials can challenge U.S. farmers because firms consider sourcing and testing alternatives in other regions, when domestic supply cannot fully meet industry requirements. This dynamic reinforces persistent barriers to diversification for Midwest farmers (Roesch-McNally et al., 2018), who may be sidelined as companies optimize varieties, contracts, and supply chains around foreign production systems rather than U.S.-based systems. Strategic innovation in pea-based products, supported by collaboration between corporations and domestic producers, and by robust policy and institutional frameworks, will be essential to open new markets, drive economic growth, and advance sustainable agriculture while enhancing regional and global food security.

Wheat

The wheat value chain reveals complex environmental, economic, and social dynamics with key challenges and opportunities. Environmentally, farmers' reduced tillage and use of cover crops and rotations improved soil health and biodiversity, interviewees noted. Stakeholders stressed the practices' role in ecological balance and wheat cultivation viability. Wheat rotations boost agrobiodiversity, alter field operations, disrupt pest-disease cycles, cut chemical inputs, enhance ecosystem resilience, and support soil organisms, insects, and wildlife for broader system health.

Wheat's role is place-specific: in Indiana, it is a double crop in the south and a cover crop in the north. Extension experts noted winter wheat typically precedes soybeans, but only where climate allows timely planting or harvest. This underscores distinguishing wheat's perceived ecological benefits from its actual use across geographies and management systems.

Economically, cooperatives and NGO collaboration improved market access and efficiency. Infrastructure investments (e.g., nearby mills), soil health, sustainability programs, and conservation incentives enhanced supply chains, created producer opportunities, and supported long-term value-chain stability. As one interviewee noted:

> We will be building a new facility with three milling units…With this expansion, we would project an additional demand of at least nine million bushels needed per year. We hope to see local farmers growing more wheat because that will certainly contribute to our mutual success, theirs and ours.

Economically, this directly impacts farmers, as one noted:

> Lots of guys who have made this a part of their rotation in some way, and economically speaking, if you can do it successfully, it's an economic home run.

Socially, strong stakeholder relationships improved food security by linking locally grown wheat to regional markets, providing stable farmer incomes, and increasing access to high-quality wheat. These connections support premium prices for sustainable production and encourage continued engagement in diversified practices, enhancing community resilience to market and environmental changes. As one interviewee highlighted:

> I think the biggest opportunity is…being able to find companies that want to pay a premium for our locally grown wheat in this area. And being able to use that sustainably, and just finding that market to give our customers extra incentives to grow wheat, raise wheat, and just have good quality.

An example of this approach is an expansion by Star of the West Milling Company, investing in a new mill in Indiana. Replicating its successful Ohio partnership with Campbell's (Schroeder, 2022; Waters, 2022), which supported sustainable agricultural practices through technical assistance, financial incentives, and infrastructure investments,

improving cover cropping adoption, market access, and long-term productivity. Interviewees noted that these partnerships strengthened the connection between farmers and brands such as Goldfish crackers, fostering pride and purpose among growers:

> We love to tell the story that the Goldfish crackers are made with Star of the West wheat. So, farmers love to grow things that actually turn into food…A lot of the 'I' states are growing corn that goes into ethanol and soybeans that goes into something else. They're not actually growing food. So, introducing growers to the food customers that they're growing for and showing them the brands and sharing some of that product with them, even if it's a box of cereal, has all been really good for us.

While this perspective emphasizes branding and consumer connection, co-ops also highlighted the benefits of these partnerships in connecting farmers to broader markets. One member of a co-op stated:

> The ultimate goal is we feel like there's a lot of value that we can deliver to our customers by helping them connect to that global food supply chain that they would not be able to do as a producer on their own, which is really the purpose of the program.

Co-ops played a key role in facilitating these connections by aggregating grain, coordinating logistics, managing contracts with end-users, and ensuring compliance with sustainability standards—services difficult for individual farmers to manage independently. Co-ops helped scale farmers' reach and integrate them into broader markets. Collaborations between partners contributed to a more resilient wheat value chain that balances environmental, economic, and social considerations.

Wheat value chains face barriers: corporations struggle to align sustainable sourcing, milling, and distribution with existing supply chains; farmers face financial, technical, and logistical issues adopting diversified crops. Collaborative models, farmer education, and support for policies and incentives are critical to overcome resistance, promote innovation, and enable sustainable wheat adoption. Financial incentives are crucial for small-grain adoption (Asprooth et al., 2023). As one interviewee noted:

> This challenge could be addressed in general by financial incentives that helped the growers add wheat crop to their farm. The other thing that we've tried to work on with, I thought about this as a policy…If we could receive the funding for a cover crop and also be harvested and sold as a food crop, that would be amazing because it's doing both purposes. And because it's not funded as nicely as corn, that would be one way that you could put it back financially into a better playing field.

Despite sustainability, financial, technical, and logistical challenges, the wheat value chain offers market opportunities. Cooperative and NGO collaboration enhances sustainability and efficiency, and creates opportunities; promoting collaborative models and sustainability programs aligned with market and environmental goals drives growth. Technical assistance to farmers, financial incentives to farmers and buyers, and processor infrastructure investments support sustainable practices and market access, as in Star of the West-Campbell's partnership and in small grains research (Asprooth et al., 2023; Sustainable Food Lab, 2023).

The wheat case study indicates that advancing sustainability initiatives and strengthening partnerships addresses challenges and seizes opportunities. Coordinated corporate, producer, and policymaker efforts—backed by financial incentives and/or enabling policies—enable wheat's significant contribution to regional and global sustainable agriculture and food security.

Oats

The reintegration of oats into production has generated economic and social impacts, alongside barriers and opportunities. Economically, the rising demand for oat-based products is shifting oat production from centering on animal feed to human consumption (Marshall et al., 2013; Mel &

Malalgoda, 2022; Yang et al., 2023). Companies such as Oatly have capitalized on this trend, seeking to source directly from U.S. growers, which enhances both market potential and producer resilience. As one pilot project farmer shared:

> It seems like the market or the business is growing with companies like Oatly…The pilot project we work with them was for them to source oats directly from the farm versus right now they source oats from like Grain Millers or somebody like that. It's a drastic change to their supply chain models, so that's why they were doing a pilot project with it.

Socially, collaboration between agricultural players such as Grain Millers, PFI, and oat growers fostered community benefits and supported economic well-being of the agricultural community in the region. These partnerships underscore the importance of collective efforts in promoting sustainable agricultural practices and economic development. Development of field days and webinars served as a collaborative knowledge-sharing approach, ensuring that stakeholders were updated on evolving market dynamics. A staff member of PFI commented:

> Field days are typically more about production, but we'll often have people come from [industries], from places and talk about their markets or what they're seeing or how they're buying or how they're using small grains. So, we do that in mostly a webinar-type format.

Oat production faces challenges: corporations deal with *Fusarium* contamination; farmers meet strict food-grade standards via careful management and investments in cleaning, sorting, and storage infrastructure. Limited local processing and the historically feed-oat focus have deprived market access; potential rejection or financial losses discourage farmer adoption.

These challenges remain partially addressed, posing barriers for farmers, especially small-scale producers, in meeting food-grade quality standards and regulations (Costantino et al., 2025). Many struggled with consistent grain quality, testing, and documentation for higher-value markets, limiting demand benefits. Meanwhile, industry opportunities grow via rising oat-product interest from health trends (Marques et al., 2026), requiring processor-farmer-agri-food collaborations. Organizations such as PFI are supporting sustainable practices and networks enabling oats in corn-soybean systems. As a Grain Millers member shared:

> We've tried to the best of our ability to provide agronomic support to growers that are wanting to add oats into the rotation…it was kind of a bit of a lost art if you want to say that. Growing oats or growing small grains for a lot of these corn/soybean growers. Now a lot of that has started to come back.

The oats case study demonstrates that emphasizing sustainability, market development, and overcoming logistical and policy barriers are essential strategies for capitalizing on the opportunities in the oat market, and thus enhancing its role in diversified agriculture in the Midwest and overall impacting the global food supply chain.

Cross-Case Analysis

The oats, peas, and wheat SES value chains in the U.S. Midwest spanned cultivation, processing, and distribution. Farmers initiated production within dominant corn-soybean rotations; processors and distributors handled post-harvest and market delivery. Cooperatives, NGOs, and Extension services provided technical support and innovation; government agencies shaped practices via incentivizing policies. Together, the actors influenced efficiency, quality, and sustainability. Understanding interactions among farmer decision making, institutional support, biophysical and market conditions—core SES components (McGinnis & Ostrom, 2014; Ostrom, 2009; Thomas Travaille et al., 2019)—is essential for explaining how diversification strategies emerge and evolve.

As a complex adaptive system, the value chain reflected dynamic interactions among resources, governance, actors, and broader political, social, economic, and ecosystem contexts. For instance, adoption of new crops was driven not only by markets and policies but also by technical assistance

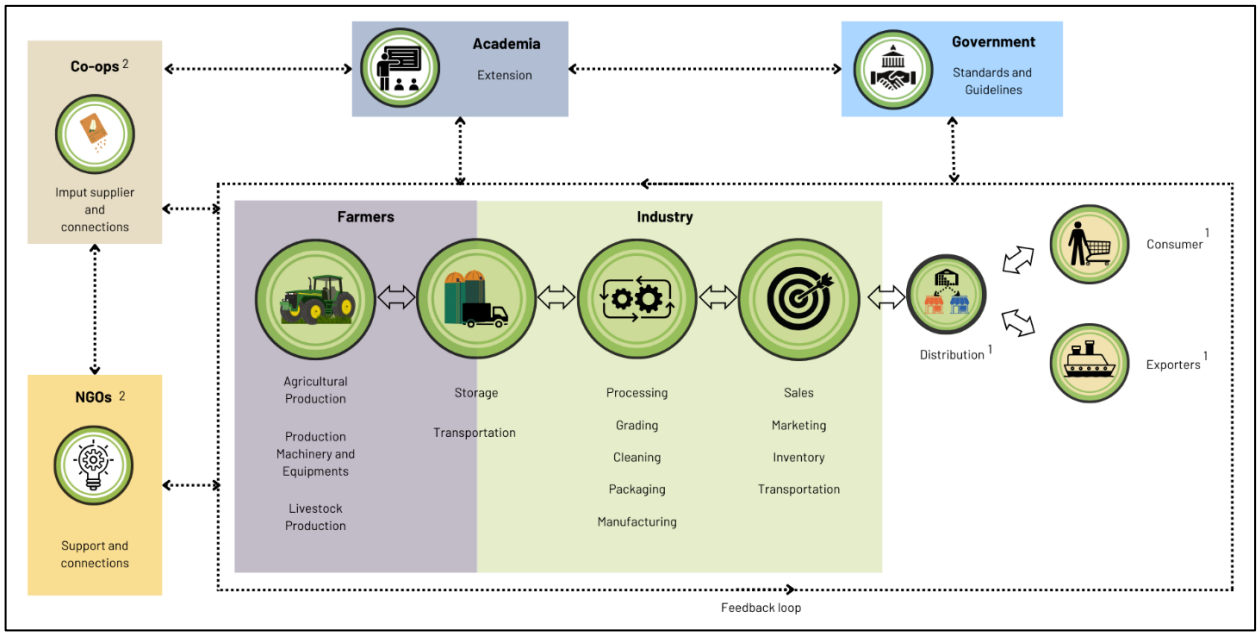
and social networks. Strengthening sustainability thus requires recognizing these interdependencies and advancing collaborative, cross-sector strategies (Figure 1).

Value-chain SES results highlight multi-level interactions. At the micro-level, farmers' beliefs, experiences, relationships, and risk perceptions drove crop adoption. At the meso-level, cooperatives, Extension services, and policies reduced barriers and contributed to trust. At the macro-level of interactions, market dynamics, national policies, and institutional frameworks (present or absent) shaped outcomes. The three interdependent levels demonstrate that interventions cascade across scales, thus emphasizing the role of adaptive, resilient strategies for sustainable diversification.

Figure 2 maps value-chain SES results to the SES framework for pea, oats, and wheat cases. In the value-chain SES, resource systems, governance systems, resource units, and actors interacted to produce outcomes for actors. Interactions affected farmer decision making, knowledge co-production, farmer-Extension collaboration, and supply-chain coordination, impacting social, ecological, and political settings. Outcomes included improved system sustainability, increased market access, and farmer innovation—all supporting ecosystem settings via improved soil health and biodiversity restoration. Active interactions enabled diversified farming adoption; non-active or weak interactions (e.g., pea production's limited local sourcing, which prompted international alternatives over local collaboration) constrained diversification, leading to maladaptation that reinforced unsustainable systems.

Figure 2 shows how agricultural diversification is shaped by market forces, actor relationships, and interactions among governance (e.g., certification standards, subsidies, conservation programs), actors (farmers, cooperatives, industry, Extension, NGOs), resource units (oats, peas, wheat), and resource systems (field conditions, crop rotations, climate). It includes broader social, economic, and political settings, such as commodity price trends,

Figure 1. Cross-case Analysis of Oats, Peas, and Wheat Value Chain



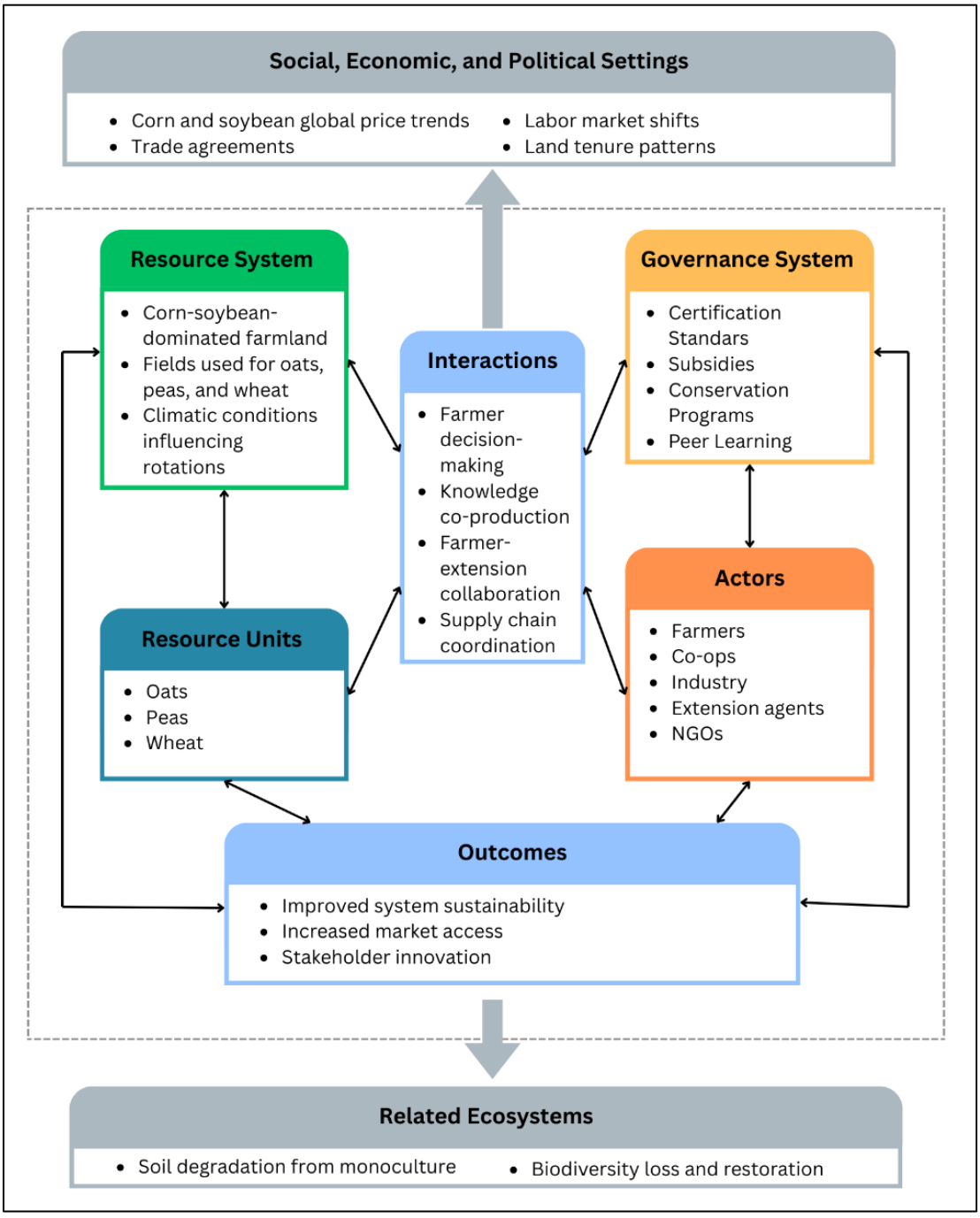
Note 1. While direct stakeholder perspectives were not obtained, the insights presented here are informed by comprehensive literature reviews and industry expertise.

Note 2. While the oats and wheat value chains provided ample evidence of connections and networking facilitated by cooperatives (Co-ops) and non-governmental organizations (NGOs), evidence is lacking regarding these supports in the pea case study. Based on the available data, this absence appears to reflect a structural characteristic of the pea value chain, particularly its more centralized, industry-driven organization, rather than solely a data limitation.

labor shifts, and land tenure, influencing system behavior over time. Figure 2 incorporates ecological feedback from monocultures (soil degradation, biodiversity loss), situating value chains in their biophysical context.

These governance structures and platforms, including Agricultural Innovation Platforms (e.g., Extension field days, commodity group meetings, farmers' networks), can enable or constrain innovation by shaping how actors interact, exchange

Figure 2. A Social-Ecological Systems (SES) Perspective on Oats, Peas, and Wheat Value Chains: Mapping Findings to the SES Framework



knowledge, and access resources (de Boon et al., 2022; Turyahikayo et al., 2017). Incorporating these institutional and relational dimensions provides insight into how farmer decisions and broader agricultural diversification trajectories are co-shaped within multi-layered governance contexts (Turyahikayo et al., 2017).

The mapping in Figure 2 enhances value-chain analysis' interpretive power by revealing underlying structures and feedback that condition innovation, adoption, and sustainability. It fosters holistic understanding of farmer decision making and landscape change (or lack thereof), reinforcing multi-scalar, adaptive strategies for resilient agricultural systems. The discussion further details cross-case value-chain SES interactions and outcomes.

Value-Chain SES Interactions

A crucial SES theme emerging from the cases was collaboration across system actors to coordinate value chains and integrate farmers more effectively. At the micro-level, adoption of alternative crops such as oats, peas, and wheat is influenced by actors' prior experiences, perceptions of risk, personal goals, and the quality of their relationships. Consistent with prior research demonstrating that farmers' decisions in the U.S. Midwest are shaped by stakeholder interactions and their previous experiences (Traldi et al., 2024), findings show strategic partnerships and networks enhance sustainability, infrastructure, and product differentiation. Weak relationships (e.g., in the pea case study) limited local diversification as well as farmer incorporation into commodity markets. Fruitful collaborations enabled transitions from commodity to higher-value food-grade markets via direct buyer ties, supply chain coordination, and technical and financial assistance. As an interviewee suggested:

> I think that's the biggest opportunity if farmers could move from growing commodities to growing food and a more direct link with consumers and the people eating the food than a big conglomerate in the middle. And I think consumer taste will evolve where they want to know where their food is coming from.

Farmer-Extension collaborations connected farmers to diversified cropping systems and equipment. University Extension provided crucial technical support, with R&D funding for equipment tailored to diversified crops (Cutforth et al., 2001). Increased storage capacity addressed growing grain storage needs. Extension training and education aided farmers' transitions to new equipment and cropping systems. As a farmer explained:

> [We] used to have yellow pea field days [organized by university Extension] because there was lots of research going on in western half of the state with yellow peas. It seems like they've pretty much stopped them. I'm thinking because of the change of administration or just ran out of research dollars…I'm guessing a lot of it has to do with the commodity prices have changed. Corn and soybeans are the thing to grow now because the prices are better for those now.

In addition to collaboration helping farmers to integrate into the value-chain SES, collaborative interactions impacted farmer decision making, a central process within the SES that links individual agency to broader system dynamics. Farmer adoption of oats, peas, or wheat was not made in isolation but was shaped by biophysical, social, and institutional factors: ecological conditions (soil health, climate suitability), market incentives, risk perceptions, and personal and community values. Interviewees noted diversification often came from perceived benefits such as improved soil fertility, reduced input dependence, or conservation alignment—but faced constraints from market viability uncertainties, input availability, and limited policy support. These dynamics reflect SES action situations, in which decisions emerge from interactions among actors (farmers), governance (programs and/or policies), and ecological contexts (fields, climate, pests). As one farmer explained:

> Lots of guys who have made this a part of their rotation in some way, and economically speaking, if you can do it successfully, it's an economic home run. And then on top of that, soil health-wise, it's a lot better than just raising

> just beans or just wheat that year. So, a lot of stuff, I guess, but diversifying would be the big takeaway.

Knowledge co-production—a key SES interaction—shaped adaptive, informed value- chain systems. It involved shared knowledge development and exchange among farmers, buyers, agronomists, NGOs, and Extension professionals via sustained platforms such as field days, farmer networks, and buyer-producer forums. These aligned production with market needs and improved on-farm decisions, and built cross-chain trust. Unlike one-way technical transfer, they created feedback loops merging experiential, scientific, and market knowledge for innovation and joint problem-solving. As one PFI member described:

> Field days are typically more about production, but we'll often have people come from [Industries], and talk about their markets or what they're seeing or how they're buying or how they're using small grains.

These interactions—spanning supply-chain coordination, farmer-Extension collaboration, farmer decision making, and knowledge co-production—underscore the dynamic and interconnected nature of the value-chain SES. Together, they demonstrate how multi-actor engagement fosters adaptability, supports transitions to diversified markets, and strengthens the resilience of farming systems. At the meso-level, these interactions facilitate trust and shared learning so that institutional support emerges, reducing transaction costs, enhancing technical capacity, and enabling adaptive responses to ecological variability and market uncertainty (Berkes, 2017; Lebel et al., 2006). By understanding and enhancing these interactions, stakeholders can more effectively co-create sustainable and inclusive agricultural value chains.

Finally, at the macro-level, resource systems—agricultural landscapes and the embedded commodity value chains—are shaped by external drivers like trade policy, input costs, and climate variability. For example, fluctuating corn and soybean prices, interlinked globally, create feedback loops influencing farmer decisions and market behavior. These uncontrollable macroeconomic signals cascade across the SES, underscoring the role of multi-scalar interactions in outcomes. Recognizing these dynamics is essential for resilient, scalable, context-responsive interventions prioritizing systems-based approaches over individual practices (Morris et al., 2021).

Value-Chain SES Outcomes

Our value-chain SES analysis shows how diversified crop systems—via collaboration, governance, and evolving markets—enabled alternative crop markets in the U.S. Midwest. Outcomes fostered systemic transformation beyond individual benefits, as new relationships, trust, and shared sustainability goals emerged.

A key outcome across all crop cases is enhanced system sustainability. Diversifying with oats, peas, and wheat strengthened ecological resilience by improving soil health, reducing input dependence, and increasing biodiversity. Stakeholders emphasized that this ecological feedback created more adaptive farming systems, better equipped to handle climate and market fluctuations:

> In the US is oat's opportunity to impact crop rotations, success for growers. I mean, there's been tons of cases were adding oats to your rotation for growers helps in a whole variety of pest reduction, weed suppression, changes a lot of those pest cycles for improvement, both in your corn and soybeans, which might be your more significant cash crops.

Case studies also show increased market access by repositioning oats, peas, and wheat from low-value commodities to food-grade crops (Cargill, 2018; Waters, 2022; Watrous, 2021). Interviewees noted that transition to higher quality crops opened premium markets valuing sustainability, traceability, and quality. These shifts arose from buyer demand, farmer readiness, and supporting infrastructure enabling value differentiation.

Strategic buyer-producer relationships shaped these markets. Weak ties, as in peas—where buyers couldn't source locally and pursued international options instead of enhancing local supply—constrained diversification by relying on non-local

sources (Roesch-McNally et al., 2018), an outcome consistent with the SES literature (Bodin & Crona, 2009; Jordan et al., 2023). In contrast, infrastructure investments, direct contracting, and certification programs lowered entry barriers and built long-term trust. As one actor explained:

> I think the biggest opportunity is being able to find companies that want to pay a premium for our locally grown wheat in this area. And being able to use that sustainably, and just finding that market to give our customers extra incentives to grow wheat, raise wheat, and just have good quality.

These cases show value chains evolving via mutual economic and environmental value recognition, creating feedback loops incentivizing diversification. Collaboration and innovation fostered premium market access, establishing durable place-based markets. Alternative crop adoption in corn-soybean systems requires multi-level value chain and incentive restructuring (Meynard et al., 2018; Traldi et al., 2024), including development of social infrastructure (trusted networks, advisory services), physical infrastructure (regional processing and storage), and policy frameworks supporting ecological intensification and market diversification. The SES framework reveals how subsystem interactions drive system adaptability and sustainability.

Finally, in the process of transitioning toward new markets, actors engaged in continuous innovation to navigate agronomic and economic uncertainties, which included adapting production techniques for emerging crops, experimenting with crop rotations, and developing on-farm storage or handling capabilities. As new markets offered uncertain yet promising returns, farmers played an important role in testing the viability of crops. One interviewee reflected on this adaptability:

> The soy business is very mature. It's been around for a really long time. It's not a new innovative idea by any means…And so, they sidetracked and started to dabble with the peas and see if they could create a pea protein.

This example illustrates how innovation is not only technical but strategic—shifting attention to underutilized crops and niche markets as an avenue for differentiation and resilience. Innovation became a key mechanism through which stakeholders actively participated in shaping and expanding diversified market systems.

Together, improved system sustainability, increased market access, and stakeholder innovation reveal how diversified crop markets emerge via gradual experimentation, relationship-building, and structural support. Supportive institutional and relational infrastructures—Extension programs, strategic partnerships, private sector alliances, farmer networks—provided the backbone, offering knowledge, resources, and trust to reduce uncertainty and to align actors. Thus, diversification represents not just agronomic and economic shifts but socio-institutional achievements rooted in collaboration, responsiveness, and shared vision.

Conclusions

This study reveals system dynamics in U.S. Corn Belt diversification markets, showing how stakeholder collaboration, social-physical infrastructure, market access, and sustainable practices interact to drive farm and landscape transitions. The SES framework demonstrates how actors embedded in multi-level social, institutional, and environmental networks guide decision making and enable or constrain local diversification.

Cross-case analysis confirms that value chains are complex adaptive systems where sustainability, market access, and farmer innovation emerge from processor-buyer-researcher-farmer interactions, supported by infrastructure and governance. Weak relationships between groups and lack of enabling policies constrain these outcomes, reinforcing unsustainable systems and limiting local diversification. These findings are crucial for informing efforts to advance agricultural diversification and maintain resilient markets that support farmers and buyers. By using an SES approach as opposed to a traditional value-chain approach to framing these findings, this research highlights how social and ecological factors can limit or enable economic value chains and related production (Loomis et al., 2026; Pradhan et al., 2022), emphasizing the interconnectedness and interdependence of economic,

political, social, and ecological conditions. Several limitations should be considered: the study focused on a specific set of crops (oats, peas, and wheat) in select regions, relied primarily on interviews, and may not capture long-term trends or perspectives of conventional farmers not engaged in diversification. Despite limitations, this study advances understanding of collaboration and sustainability in agricultural value chains and forms part of the larger Diverse Corn Belt project,[2] which addresses these via complementary investigations.

Future research should connect micro-level farmer decisions with meso-level collaborations—such as cooperatives, nonprofit alliances, and enabling policies—and macro-level market dynamics to better understand how diversified value chains are constructed, scaled, and sustained. Through examining these interactions, diversification can be seen not merely as a crop substitution but as a socio-ecological reorganization, where micro-level decisions and macro-level trends converge to generate new pathways for resilient agricultural systems in the U.S. Corn Belt and beyond. Future policy and practitioner efforts can aid in overcoming persisting challenges like financial and technical limitations related to the adoption of diversified products in farming systems. Establishing new or redirecting existing financial incentives (e.g., Farm Bill conservation programs) to prioritize the production of diversified products is necessary to address farmers' financial constraints, enable product adoption, and support a robust product value chain. Technical assistance provided by Extension services, NGOs, industry, and other groups can be geared towards filling knowledge gaps around producing diversified products and further enabling their adoption by farmers.

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