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EDITED BY
Jose G. Franco,
Agricultural Research Service (USDA),
United States

REVIEWED BY
Kelly Mercier,
United States Department of Agriculture,
United States
Alan Rotz,
United States Department of Agriculture
(USDA), United States

*CORRESPONDENCE
Colin Cureton
✉ cure0012@umn.edu

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Towards a practical theory for commercializing novel continuous living cover crops: a conceptual review through the lens of Kernza perennial grain, 2019–2022

Colin Cureton[1]*, Tessa E. Peters[2], Sophia Skelly[2], Constance Carlson[3], Tara Conway[1], Nicole Tautges[4], Aaron Reser[5] and Nicholas R. Jordan[1]

[1]Forever Green Initiative, Department of Agronomy and Plant Genetics, University of Minnesota, Saint Paul, MN, United States, [2]The Land Institute, Salina, KS, United States, [3]Regional Sustainable Development Partnerships, University of Minnesota, Saint Paul, MN, United States, [4]Michael Fields Agricultural Institute, East Troy, WI, United States, [5]Green Lands Blue Waters, University of Minnesota, Saint Paul, MN, United States

As agricultural scientists rapidly develop and deploy novel continuous living cover (CLC) crops and cropping systems such as perennial grains, a growing number of intermediaries are engaged in advancing the commercialization, adoption, and scaling of these novel CLC crops. However, these commercialization practitioners lack a conceptual and practical roadmap to help them achieve success. Through key concept review and practice narratives, this article presents the firsthand experience of primarily non-academic staff at several key public and nonprofit agricultural innovation platforms between 2019 and 2022 that have held core institutional responsibilities for facilitating the commercialization, adoption, and scaling of Kernza® perennial grain, North America's first commercially-viable perennial grain crop. Reviews of key concepts identified as relevant to the practice of commercializing novel continuous living cover crops are interwoven with practice narratives of the Kernza commercialization process through the lens of each concept, demonstrating the ways in which these concepts translate to specific activities, methods, and strategies, also noting remaining gaps, limitations, and areas for growth and learning. This narrative can move the growing community of CLC intermediaries and innovation brokers toward a 'practical theory' of CLC commercialization that lies at the intersection of technology transfer and adoption, innovation, and agri-food systems change processes. Such conceptual orientation and practical guidance stands to improve the efficacy of novel CLC crop commercialization intermediaries, accelerate wider efforts of agricultural innovation platforms to rapidly advance CLC agriculture, and provide fertile ground for further applied research.

KEYWORDS

continuous living cover, commercialization, stewardship, perennial grains, innovation, technology transfer, intermediaries, sustainability transitions

1. Introduction to commercialization of novel perennial and continuous living cover crops

Perennial and continuous living cover (CLC) crops and cropping systems provide year-round ground cover and long-lived roots, offering a host of water, soil health, biodiversity, pollinator, and climate benefits. At a landscape scale, CLC agriculture can better protect critical natural resources compared to agricultural systems based primarily on summer annual crops (Culman et al., 2013; Eberle et al., 2015; Basche and DeLonge, 2017; Jungers et al., 2019). CLC advocates' implicit theory of change is founded in the idea that new and improved CLC crops and cropping systems must be economically viable and significantly, if not primarily, market-driven. This indicates the need for agricultural production, supply chains, and markets for CLC crops along with significant and ongoing research and development to improve the crops and cropping systems. This process must navigate the notoriously high capital costs, high risk, path-dependency, and low-margin nature of agriculture and the food sector. Compounding issues arise when developing novel CLC crops such as perennial grains compared to, for example, alfalfa, grasslands, and existing winter-hardy crops since those crops do not require additional supply chain and infrastructure development. Social and philosophical dimensions of agriculture are also invoked, proposed, and negotiated as institutions developing novel CLC crops for economic, environmental, and social impact move their research and implementation forward in the world with thousands of actors with diverse interests and perspectives. Novel CLC crops also require incorporation in policy frameworks and in some cases more significant policy innovations. While the benefits of a CLC agricultural system would be tremendous, challenges abound for arriving at this CLC landscape.

Institutions developing CLC crops and systems therefore have their work cut out for them. Following several hard-fought decades of research and development on a novel CLC crop or cropping system, proponents are confronted with a series of systemic technical, economic, regulatory, and cultural barriers to deploying this new crop and its products in the marketplace. Research institutions understand that developing a new crop or cropping system requires dozens of scientists working in well-organized transdisciplinary teams. What's becoming increasingly clear is that it also requires well-supported teams to commercialize novel CLC crops and systems. This process includes crop development scientists as well as growers, engineers, chemists, food scientists, marketers, economists, start-ups, established firms, finance/investors, policymakers, and, the focus of this article, commercialization staff whose purpose it is to weave these actors together to support the adoption and scaling process for novel CLC crops and systems. Commercialization staffs' work stands to benefit from both guiding concepts and practices informed by peers engaged in this work.

Kernza® Perennial Grain is furthest along in navigating these commercialization challenges. Several institutions are collaboratively developing novel perennial grain and CLC crops and systems in the pursuit of a much wider sustainability transition in the agri-food system. Kernza is the trade name of grain, seed, and products derived from varieties of Intermediate Wheatgrass (IWG), *Thinopyrum intermedium*, improved for use as a food-grade grain. IWG is a Eurasian forage grass initially brought to the United States in the early 1900's. It has been under development as a commercially-viable perennial grain crop for over 30 years by The Rodale Institute, The Land Institute (TLI), the University of Minnesota (UMN), and increasingly other institutions across the world. Since its inception, the Kernza trademark has been owned and managed by TLI and, since 2019, effort has been made to increase the involvement of other early-adopter institutions, growers, processors and end-users in exploring how to manage the trademark more collaboratively.

The relationship between TLI and the UMN is woven together by long-running personal, professional, and institutional relationships. UMN and several of its respective entities, such as the Forever Green Initiative (FGI) and Green Lands Blue Waters (GLBW), hold critical roles in developing CLC crops and systems, developing networks to advance CLC, and supporting the commercialization, adoption, and scaling of CLC agriculture. The education and professional development of key researchers in the Upper Midwest was strongly influenced or supported by TLI, and vice versa. What had been long-running informal or project-specific research collaborations were recently crystallized through the 2020 funding of a major five-year project, KernzaCAP, funded by the United States Department of Agriculture (USDA), National Institute For Agriculture, Sustainable Agricultural Systems Coordinated Agricultural Projects (CAP) program. KernzaCAP takes an integrative approach to further developing Kernza's germplasm, agronomy, food science, understanding of ecosystem services, education, extension, policy, and supply chains and economics. Separate philanthropic and public funding has provided a preceding and ongoing base of support for commercialization staff.

The experience of commercialization and stewardship staff during this critical phase of Kernza perennial grain's development can provide valuable insights for CLC crops and systems that are soon to follow. This paper provides an account of the experience of a self-organized team representing UMN, TLI, and the Michael Field Agricultural Institute (a Wisconsin-based nonprofit) that have led many core commercialization activities for Kernza since 2019 (Table 1). There is a growing recognition that new tools such as perennial grains and oilseeds, woody perennials, and winter annuals will be valuable for advancing the cross-societal commitments to soil health and regenerative agriculture (Crews et al., 2018). The ecosystem of actors advancing CLC continues to expand, and it is critical that these actors have a combination of theoretical framing and practical guidance provided by peer practitioners that includes clear methodologies and strategies that can be iterated and adapted across CLC crops. This article is intended to provide an orientation to the nature of CLC crop commercialization as well as practical guidance on strategies, approach, timelines, mindset, skill sets, and other aspects of CLC commercialization. Taken together, this review may move the CLC community toward what Berkman and Wilson (2021) describe as a 'practical theory' for novel CLC crop commercialization. Such practical theories reside between basic and applied theory, and suggest actionable steps toward solving a problem that currently exists in a particular context in the real world. Practical theory recognizes that theory and practice are not a dichotomy, but rather co-constitutive (Miller and King, 1998). The problem of effectively supporting the launch, adoption, and scaling of novel crops with unique agronomic, physical, environmental, etc. characteristics is one such problem around which actionable steps are needed, the practice of which can improve our understanding of future iterations of novel CLC crop commercialization.

TABLE 1 Commercialization milestones for Kernza® perennial grain.

Year	Event
2009	The Land Institute files for "Kernza" trademark (officially registered in 2011).
2010	Harvest of the first large-scale Kernza field (30 acres) in Kansas occurs, filling a semi-truck with grain, a key proof-of-concept moment.
2011	Food science research begins at the University of Minnesota, launching research in support of Kernza product innovation.
2013	Birchwood Cafe in Minneapolis, MN adds a savory Kernza waffle to the menu, the first Kernza product on a restaurant menu.
2014	The first grower contracts for commercial Kernza production (with grass seed growers in northern Minnesota) are established by Patagonia Provisions.
2016	An early version of a Kernza Grower Guide is made available to farmers and technical assistance providers.
2016	Long Root Ale from Patagonia Provisions becomes the first packaged Kernza product.
2016	General Mills begins experimenting with Kernza in an R&D facility for product development; leading to future launch of limited-run Cascadian Farm brand cereals.
2018	Sustain-A-Grain, a farmer-centered company in Kansas is founded and begins to sell Kernza seed.
2020	Direct-to-consumer Kernza flour and grain sales are made possible online via a new Kernza processing and food brand, Perennial Pantry.
2021	A group of Kernza growers founds The Perennial Promise Grower's Cooperative.
2022	State support for Kernza supply chain partners becomes a new opportunity when the Minnesota Legislature approves a Continuous Living Cover Value Chain Development Fund.
2022	Stakeholder driven discussions begin to explore the formation of a Kernza Stewards Alliance (KSA).

Adapted from KernzaCAP (2023).

First, this paper provides a brief introduction to the early, pre-2019 commercialization of Kernza, which contextualizes the concerted cross-institutional support for commercialization that followed. The remainder of the paper is devoted to an overview of concepts that elucidate and inform the function of commercialization staff in this collaborative endeavor with accompanying narratives from 2019–2022 that bridge these theories into practice, contributing to a practical theory for novel CLC crop commercialization (Table 2). Early commercialization of Kernza perennial grain, pre-2019.

Following over 20 years of basic research and development on IWG to breed for its viability as a perennial grain crop, the food industry and wider society began to take note of the potential for perennial grains. Early commercialization activity was characterized by a small group of champions (farmers, food businesses and a wide array of other dedicated partners) working through the early hurdles together in committed yet challenging attempts to bring Kernza to market. These early champions demonstrated that growing and creating products with Kernza was possible. As early as 2008, a national, sustainability-minded food company conducted recipe testing on Kernza tortillas, culminating in a pilot at one store location. Their engagement catalyzed commercial activity at TLI and beyond in the ensuing decade. In 2013, a Minneapolis-based cafe began featuring Kernza waffles on their menu. This provided proof of concept to Minnesota cross-sector stakeholders with budding interest in Kernza, opening the door to new consumer awareness and additional food businesses piloting Kernza, as well as catching the interest of policymakers and nonprofits.

Considering commercialization alongside basic research was not accidental. IWG germplasm development and associated research (e.g., agronomics, food science) at TLI and UMN in the 2010s was coupled with an ecosystem of Minnesota partners such as the Minnesota Institute for Sustainable Agriculture and GLBW to help facilitate early farmer and commercial piloting in Minnesota and the wider Midwest. For Kernza to emerge beyond the academic environment, such entities were needed to serve key logistical roles, including distribution of seed and grain to businesses and farmers and information dissemination, and the cautious but dogged cheerleading role for the potential of the crop. Early commercial experimentation with Kernza, like other novel crops, involved a tremendous amount of troubleshooting such that it was unlikely to be profitable for farmers or food businesses to trial the crop without support. Additional troubleshooting was required to process the grain, which includes cleaning, dehulling, testing for appropriate seed and grain quality, and in some cases milling, before an end user could consider working with the ingredient. The experience of these early actors foreshadowed the need for and functions of the dedicated Kernza commercialization staff that would follow in later years.

Early Kernza commercialization would not have happened without the boldness of a few key farmer and food business leaders willing to go the extra mile to trial a risky and experimental grain. The first grower contracts were established with Minnesota producers in 2014 and by 2015, several Minnesota businesses were piloting Kernza products (e.g., beer, noodles, crackers) and a local mill soon took on milling and distribution. In 2016, the first widely distributed Kernza product, a Kernza beer, hit regional West Coast markets, a major multinational company was testing Kernza as an ingredient at their research and development (R&D) facility, and the media were taking note. The ensuing excitement about Kernza resulted in an influx of interest from businesses and farmers alike in 2016 and 2017.

It soon became clear that the entities developing Kernza perennial grain needed support to facilitate commercialization activities. From 2016 to 2018, TLI contracted a small grain logistics company to increase Kernza acreage by working with existing growers and enlisting new ones. During this phase, growers faced hurdles related to early-stage germplasm, accessing seed, and a lack of sufficient agronomic knowledge and support. Plantings were geographically spread out and relationships with processing partners and buyers were nascent. In the absence of efficient systems to buy, clean, and market Kernza grain and provide farmer technical assistance, the logistics company also stepped into those roles which was a tall order.

The challenges encountered by this company and the wider Kernza community were multifaceted and capacity was limited, straining the existing goodwill of Kernza stakeholders. However, many early partners remained committed and the successes with Kernza during these years piqued the interest of additional restaurants, smaller companies, and major industry. Efforts to keep good communication flowing between stakeholders and to emphasize a

TABLE 2 Key concepts underpinning commercialization of new crops such as Kernza®.

Concept	Definition	Sub-concepts	Implementation/milestones
Technology Transfer	The sharing or introduction of a technology followed by the spread or expanded utilization of the new technology Molnar and Jolly (1988)	Intellectual property, variety releases, and licensing	• Release of first commercial Kernza variety, MN-Clearwater • Development of co-exclusive licenses to three regional seed companies
		Commercial trademark	• Development of Kernza trademark • Built transparent process of grower vetting and trademark licensing • Annual reevaluation of vetting and licensing priorities
		Physical transfer of Kernza seed and grain	• Began highly informally • Evolved into formalized multi-partner process reliant on request intakes and material transfer agreements • Early commercial sales conducted through unique cross-sector partnership with state crop improvement association and seed company • Increasingly, requests are fulfilled by market partners as business development opportunities rather than solely university and NGO partners as technology transfer • Commercial sales of seed and grain by private actors replace institutional tech transfer roles
		Education and programming	• Annual call series and development of Kernza informational resources to provide grower support • Development of communication network among early-adopter Kernza growers • Formation of state-supported Kernza technical assistance team • Development of technical resources to support technology adoption along the entire supply chain, spanning from dehulling to baking
		De-risking support	• Developing and deploying State support to provide producers with environmental benefit payments, risk management payments, seed and grain testing services, and agronomic support • Developing and piloting a value chain development fund to support post-farmgate entrepreneurs and businesses
Innovation	The commercial introduction of a new product Perez (2010), as opposed to the invention produced by science and technology. Understood here as the ways in which Kernza and Kernza's associated knowledge find footing in the world in the form of viable products, businesses, and new value propositions, and how Kernza, in turn, informs institutional, public, firm, and consumer priorities, assumptions, and possibilities.	Innovation Systems	• Intentional cultivation of a regional system that encompasses many of the actors needed to construct innovative grain systems • System supported by consistent strategic communication and coordination • Innovation system enabled by strong social capital, civic engagement, and state investment in MN.
		Innovation Management	• Communicating and integrating learnings, needs, and challenges across R&D, supply chains, and other stakeholders. • Multi-stakeholder collaboration established a baseline understanding of harvest methods, mycotoxin levels, cleanout rates, and more. • Initiated collaborative project to assess evolving harvesting, seed cleaning, processing, milling, and sifting needs in response to improved Kernza germplasm.
Intermediaries	Actors and institutions that positively influence sustainability transition processes by linking entities and their related resources and skills, creating new collaborations across niche technologies like Kernza, linking technologies to markets, and generally creating momentum for system change	Innovation brokers	• An early reserve of Kernza from state-supported water trials was provided to Kernza entrepreneurs as 'start-up grain', which helped them launch a business that is on the forefront of Kernza innovation • Dozens of dialogs with prospective end-user firms pursuing innovations in product development and marketing, linking them to technical expertise and high-quality information.
		Systemic intermediary	• Navigating tweaks to policy regimes to better incorporate novel crops like Kernza

(Continued)

TABLE 2 (Continued)

Concept	Definition	Sub-concepts	Implementation/milestones
Legitimacy	The broad acceptance and wide adoption of Kernza Montenegro de Wit and Iles (2016). Thick legitimacy requires the passing of credibility tests in multiple arenas, ranging from legal to scientific.	Scientific	• Creating Kernza meetings where practitioners and researchers can share findings and collaborate.
		Civic	• Developing legislated risk mitigation strategies (EECO, Conservation Stewardship Program Enhancements) • Leading development of Kernza Stewards Alliance
		Legal	• Implementing and managing trademarks • Seed contracting
		Social	• Instigating social sustainability research and sustainable supply chain evaluation
Multi-level perspective & sustainability transitions	Transitions to qualitatively different, more sustainable systems is immensely difficult and requires concerted alignment of niche and	Niche-regime interactions	• Development of Forever Green Partnership • Implementation of LEN • Incorporating Kernza into key cultural institutions, e.g., state and county fairs
		Landscape-regime interactions	• USDA Farm Service Agency certification of Kernza acres for conservation practices • Engaging with state agencies such as Soil and Water Conservation Districts
Scaling readiness	A framework for understanding, visualizing, and strategizing around the maturity of core innovations, and the many accompanying innovations needed for its success. Scaling readiness encompasses both evaluative measures that assess the readiness and use of an innovation and methodologies or that result in adoption, niche and regime change, and have implications for legitimacy.	Innovation packages	• Used as a framework to assess major weaknesses in overall early commercial Kernza ecosystem, like seed shortages, and develop rapid solutions

"join us on the journey" framing across early partners helped build tolerance for working through hurdles together and embracing a long-game, collaborative approach toward perennial agriculture.

Still, in our opinion there remained a general underestimation of the type of capacity and investment needed to commercialize a novel perennial grain. A cross-scale, cross-sector ecosystem of actors was needed to guide commercial activity in tandem with germplasm development, agronomic best practices, farmer support, processing R&D, product development, consumer awareness, and more. In response, key institutions developing Kernza implemented a strategy for the development of a multi-site commercialization team by late 2018, whose subsequent work is detailed across the practice narratives in this article. In turn, these narratives highlight the utility of certain theories that provide conceptual guidance to this commercialization work.

2. Conceptual review and practice narratives

Commercializing and stewarding novel CLC crops and systems such as Kernza is a fundamentally pragmatic endeavor and thus engages with knowledge and ideas to the extent that they can enable successful action (Zolfagharian et al., 2019). This paper reflects the pragmatic process, outlining the various theories that contextualize the commercialization and stewardship team's efforts to build Kernza's commercial development. Methodologically, this is described as "following the problem" with whichever approaches work. It is the complex and untidy work of bridging theory into action. Concepts from the fields of technology transfer and adoption, innovation management and brokering, intermediaries, sustainability transitions, multi-level perspective, legitimacy, and scaling readiness are relevant to understanding the nature of commercializing novel CLC crops and cropping systems and designing practical approaches to advance this practice (Table 1). An overview of these concepts is interwoven with pertinent reflection on the practice of novel CLC crop commercialization and stewardship staff through a narrative case study of key activities on Kernza commercialization from 2019–2022. This interweaving illustrates how conceptual frames have proven relevant in practice, and notes areas in need of further conceptual development, in light of our practical experience. While hundreds of individuals and entities have contributed to Kernza's early commercial development, only authoring entities are named to respect the confidentiality and potentially varying perspectives of these many other stakeholders.

2.1. Technology transfer and adoption in CLC

Before new agricultural technologies can be scaled, they must be successfully adopted. Prior to being adopted, these technologies must be transferred. Thus, any entity seeking to develop and scale a technology such as CLC crops must, at a minimum, have effective technology transfer and adoption strategies. Too often, the opportunity and promises of innovation and scale obfuscate the detailed, nuanced, specific work of effective technology transfer and adoption that necessarily precedes achieving larger impact.

Molnar and Jolly (1988) define technology transfer as the sharing or introduction of a technology followed by the spread or expanded utilization of the new technology, generally proceeding from the central points to the periphery. Technology transfer is explicitly a multi-level process of communication involving a variety of senders and receivers of ideas and materials. Moreover, community absorption of new technology involves significant selection or modification in the course of adaptation to local conditions and preferences.

Technology transfer in agriculture has been closely studied for nearly a hundred years. Comprehensive reviews of technology transfer between universities, industry, and society detail its many challenges and characteristics (Hoenen et al., 2018). The nature of agriculture presents numerous challenges to technology transfer, including protracted timelines, the need for regional adaptation of crop varieties and cropping systems, and complications due to weather, soil type, pests, equipment, management, and markets. Technology transfer is a nuanced, layered process that extends well beyond patenting and licensing. It is also influenced by grower attitudes and resources, industry and university fields, inventor motivations, firm characteristics and culture, the structure of cross-sector collaboration, and staffing (*Ibid*). Cramb (2000) notes, "successful adoption depends on more than careful planning in research and the use of appropriate methodologies in extension. It depends on the timely formation of coalitions of key actors whose interests converge sufficiently that they can focus their resources and efforts on achieving change in agricultural systems." While this article focuses primarily on commercialization staff's roles and activities, the importance of these key actor coalitions across growers, supply chain actors, and end-users cannot be overstated and deserve subsequent inquiry in their own right. Recent research emphasizes the role of agricultural scientists as well in the political work of constructive collective action to address grand challenges, such as those targeted by CLC crops and systems (Jordan et al., 2021).

Studies of technology transfer have dispelled simple unidirectional processes (Schmoch et al., 1997), transfer of new technologies free from the need for complementary innovations (Sartas et al., 2020), and highlighted that new technologies are bound up with social and institutional processes. The field of technology transfer and related critique led to subsequent conceptual development of the socio-technical system (Geels, 2004) and more recently scaling readiness (Sartas et al., 2020). The classical notion of technology transfer has been criticized as inadequate for understanding the sources and solutions to increasingly complex contemporary problems, giving way to understanding of agricultural innovation systems and "intermediaries" as innovation facilitators and brokers–concepts introduced in subsequent sections (Koutsouris, 2018). Despite these criticisms, the concept of technology transfer can be helpful for highlighting the specific activities of CLC commercialization staff at the point of technology 'handoff,' details which are at risk of being lost in more complex theoretical framing.

Barriers to adopting agricultural conservation practices, including living cover crops, are well documented (Roesch-McNally et al., 2018; Prokopy et al., 2019). These findings and the associated strategies for overcoming the barriers, such as technical assistance (Peters et al., 2021), can reasonably be assumed to extend to other CLC crops, though more research is warranted. Practical barriers to the adoption of conservation practices in US agriculture include farmland lease terms and rental dynamics, partial information, cognitive and interpersonal factors, and financial concerns. These barriers vary by actor in the agricultural system, such as non-operating landowners versus operators (Ranjan et al., 2019) and relative to gender (Carter, 2019). Field tours, or field days, can be an effective strategy to support grower adoption, though the design of such projects and attendee characteristics are important factors in shaping new technology adoption (Forte-Gardner et al., 2004).

Since 2019, a substantial portion of Kernza commercialization staff's activities have focused on detailed technology transfer and adoption strategies for Kernza perennial grain. To do this, they interface closely with researchers, growers, industry, university technology transfer office staff, agricultural utilization experts, community partners, and others. Between 2019 and 2022, the primary strategies to support technology transfer and adoption among Kernza commercialization staff included: (1) Intellectual property, variety releases, and licensing, (2) management of a commercial trademark, (3) transfer of Kernza seed and grain to support technology adoption, and (4) educational forums, programming, resources, and dialog, and (5) de-risking support for growers and supply chain actors. To date, recruitment of growers has not been the target of a technology transfer strategy because numerous growers are interested in Kernza and recruitment has not been a limiting factor.

Perhaps because of this, little research has focused on factors informing adoption of Kernza. Lanker et al. (2020) conducted 10 in-depth interviews with early Kernza growers in 2017, finding that all were interested in the economic and ecological benefits of Kernza and had a positive attitude toward experimentation and new practices. They also found that early adopters reduced risk and cost to their operation by utilizing marginal land and resources. Growers cited the need for information on production practices, forage value, weed management, as well as economic assessments and market information–foreshadowing the need for a robust commercialization team. Wayman et al. (2019) found that across the United States and France, potential Kernza growers' interest was motivated by both farm profitability and soil health.

Cross sector coordination of intellectual property and licensing strategies was most evident leading up to and following UMN's release of the first commercial Kernza variety, MN-Clearwater between 2019 and 2022. Prior to the 2019 release, newly hired commercialization staff organized disparate stakeholders to accelerate UMN toward a release. This entailed development of internal and external communications strategies targeting early-adopter growers and stakeholders, open conference calls between the crop R&D team, early adopter growers, and other stakeholders to develop relationships and build knowledge, and physical transfer of seed. Concurrent to the release, commercialization staff coordinated with growers and researchers on variety increase lots sown around Minnesota in conjunction with water quality trials. This included post-harvest management logistics, seed and grain testing protocol, and on-boarding a new Kernza seed cleaner. In 2020, due to the disruptions of the global pandemic UMN had still not licensed the variety to actors in the marketplace and so commercialization staff filled this

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critical gap by collaborating with TLI to vet and approve growers, to execute MN-Clearwater seed sales directly to growers in partnership with the state crop improvement association, and to fulfill orders via the seed cleaner. Over 10,000 lbs. of seed were sold through this fragmented yet functional model, with roughly 1,000 acres planted in 2020, mostly in Minnesota. This was then the largest concentrated regional planting of Kernza, and roughly a five-fold increase of existing production in Minnesota.

In winter of 2020, commercialization staff developed UMN's strategy for time-delimited (four-year) co-exclusive licenses to three regional seed companies. A co-exclusive model offered growers options as well as the right balance between protection and competition for licensees. Regional seed companies were chosen because of their proximity to the Kernza research community in the Upper Midwest. Commercialization staff regularly work with licensed seed companies to promote Kernza to their customers and to troubleshoot seed supply regulations, lot certifications, and other issues. For example, in 2022 commercialization staff aggregated market information, identifying a likely seed shortage, and promoted strategies to mitigate this shortage.

The Kernza trademark, established in 2013 as a mechanism to protect the novel perennial grain in the marketplace from cooptation or dilution, has been another key tool for facilitating the technology transfer and adoption process. The Kernza trademark's benefits to include the ability to rigorously vet grower and industry partners, differentiate Kernza in the marketplace, build consumer awareness, ensure quality, regulate nefarious actors, gather market data, and build shared identity among private actors across the value chain. Downsides include additional paperwork, time and cost to manage and administer the trademark, additional nuance in achieving policy support, and Kernza stakeholders' perceptions and/or misunderstandings on the nature of trademarks. Since 2013, TLI has owned and managed the Kernza trademark, increasingly opening that process to key partners such as UMN in 2019. In 2019, the newly formed TLI-UMN commercialization team developed a transparent and consistent process of grower vetting and trademark licensing to better organize the technology adoption process, boost legitimacy, maximize chances of success in early production, and improve the resulting grain quality and overall integrity of Kernza in the marketplace. Stakeholders shared that prior to 2019 there was a real or perceived situation in which accessing Kernza seed was a murky, exclusive, or unclear process and that only the most well-connected, lucky, or persistent growers were able to access seed. Since 2019, this process has been implemented as consistently as possible to boost transparency, reduce favoritism, and pursue fairness in technology deployment while also stating institutional and organizational priorities of, for example, adoption in particular geographic regions. Trademark vetting criteria for growers are based on practical considerations of analogous experience, appropriate equipment, scale, support, and readiness. Annually, commercialization staff revisit grower vetting and licensing priorities, adapting as appropriate, and consistently communicate these priorities to the grower community. For example, in 2021 vetting guidelines were made significantly more flexible in an effort to widen accessibility and engagement with Kernza of producers with different priorities, scales, backgrounds, and experience. Since this grower application system was instituted, over 300 growers have applied for a Kernza trademark license. Notably, roughly 80% of growers applying have not been approved at first due to lack of alignment, capacity, equipment, experience, location, or other factors. While somewhat restraining rapid scaling of production, this process has established standards, transparency, and consistency for adoption of Kernza perennial grain. Moving forward, TLI is considering unique forms of steward ownership to transfer the ownership and management of the Kernza trademark to licensed Kernza growers, handlers, distributors, and makers.

Commercialization staff's third main technology transfer strategy has been physical transfer of bin-run (hull-on) seed, de-hulled grain, flour, and other Kernza ingredients. This process began highly informally with university pick-ups and parking lot hand-offs, and has since grown into a multi-partner process involving request intakes, execution of material transfer agreements (MTAs), fulfillment of sample requests by university and nonprofit partners, and, increasingly, an uptake of this process by market partners as a means of customer relations and market development. Since 2019, thousands of pounds of sample Kernza perennial grain have been transferred for experimentation in cleaning, processing, milling, sifting, brewing, distilling, baking, feed trials, and other food and non-food product development activities. Such transfers help potential partners move forward with Kernza while physically stitching together sustainability transition relationships and processes across sectors. The physical transfer process requires consistent and clean communication, legal support for MTAs, small-scale food grade cleaning equipment and storage, packaging, and fulfillment. Receiving entities often require technical support from food scientists and other entrepreneurs, requiring a degree of cooperation across sectors and in some cases direct competitors. This experience suggests that a system for physical distribution of sample grains is neither quick, simple, cheap, nor easy, and is fundamentally collaborative.

The fourth main technology transfer strategy between 2019 and 2022 for Kernza perennial grain has been educational forums, programming, resources, and dialog. Tactics include: (1) formal and informal cross-sector partnerships with researchers, industry, growers, and entrepreneurs, (2) development and dissemination of technical information and support to growers, processors, and end-users, and (3) winter call series, summer field days, and increasingly visible public events. Foundational resources include a winter series of annual documents and associated call-series and/or in-person events. Annual documents lay out the state of Kernza, institutional priorities for the coming year, how to become a Kernza grower, and how to access seed, technical support available, and other resources. An accompanying annual call series, initially oriented toward growers, was started in the summer of 2019 as MN-Clearwater was poised for commercial release. These were structured as relatively open conference calls between UMN and TLI Kernza breeders, agronomists, environmental scientists, and early adopter growers. These conversations helped to build trust among early adopter growers and institutional actors.

In early 2020, UMN again hosted a series of conference calls with Minnesota growers who either had Kernza growing on their farms or were interested in growing Kernza. These calls continued informally between UMN and early-adopter growers, which created a runway for growers to move from curious participants to engaged leaders. The calls formed a foundation of communication among early adopter Kernza producers in the region, which growers subsequently took the lead on, not long after forming a producer-owned and led cooperative. Growers began taking on peer-to-peer technical assistance and new grower mentor roles. A state-supported Kernza technical assistance team was formed soon after with coop leadership, community partners, a part-time specialist, and university and NGO researchers. Taken together, these practices provided foundational resources for growers to successfully plant, harvest and market Kernza, but also created a feedback loop between growers and researchers built on trust and clear communication. This vignette demonstrates how well-organized technology transfer strategies can foster successful technology adoption, subsequent grower-led diffusion, and commercial activity.

A Minnesota-based agricultural utilization entity has been a critical partner in the development of technical specifications and associated resources regarding processing, food science, forage and co-product uses, business development, and other applications. These efforts have been critical to effective technology transfer and adoption across the value-chain. Several phases of critical support from a State of Minnesota legislative commission helped weave together development of Kernza's agronomic management, water quality impacts, proof-of-concept pilot commercial production, and baseline agricultural utilization information. Technical resources developed through these projects are publicly-available and provide important, often more rare support for technology adoption among value chain actors seeking to clean, dehull, mill, malt, brew, bake, or otherwise utilize Kernza. Their role and impact suggests that technology transfer support must extend well beyond the farmgate in order for markets to develop, thereby supporting grower uptake.

Finally, the fifth main strategy for supporting technology adoption of Kernza perennial grain has been several channels of de-risking support. The first channel deploys support from State of Minnesota to early adopter Kernza growers to maximize the chances of commercial success and protect water quality in areas with vulnerable and/or impaired drinking water. These regions have been dubbed Economic and Environmental Clusters of Opportunity, or EECOs, with the goal of concentrating production in these areas to maximize environmental benefit, achieve economic efficiencies, and foster regional innovation and community leadership. This Forever Green EECO Implementation program provides both an environmental benefit payment and risk management payment in the event of losses taken on-farm or in the market, coupled with a diverse technical assistance team, seed and grain quality testing services, and targeted supplies and equipment. A forthcoming channel of support results from a 2021 policy initiative. This initiative is prototyping a new CLC value-chain development fund that supports entrepreneurs and businesses beyond the farmgate to adopt and/or scale-up their work with Kernza perennial grain and several other leading-edge CLC crops and systems. The initiative was funded by the Minnesota state government because of well-organized advocacy by a coalition of CLC-focused entrepreneurs and a separate coalition of environmental advocacy groups, supported by UMN and the Minnesota Department of Agriculture.

This overview of the commercialization team's technology transfer activities confirms the well-established definition of technology transfer as multi-level, multi-actor, and multi-directional. Technology transfer of a novel CLC crop is ongoing and occurs across the value chain. The technology transfer and adoption process requires trusting relationships, well-organized teams able to traverse a wide range of stakeholders, topics, and skills, technical knowledge or the ability to marshal it where needed, the design and execution of educational and outreach resources, and the development of strategic and transparent frameworks to guide important commercialization processes. These frameworks include intellectual property and variety release strategies, sample grain provision to end-users, development and management of seed and grain quality testing systems, strategic deployment of grain reserves, management of trademark and identity preserved programs where applicable, ongoing cross-sector partnerships, and outreach and engagement strategies. Before anyone can reasonably think about scaling, the above must happen while navigating the many standard challenges of agriculture as well as the new hurdles of bringing a paradigm-shifting, regime-challenging novel CLC crop to market. While the initial technology transfer process may be considered over at some point, commercialization staff expect that these technology transfer strategies will roll directly into the longer-term processes of innovation management and sustainability transitions, discussed later in the paper.

2.2. The role of innovation in the transition to CLC: definition, trajectories, rhythms, management, and regional systems

Understanding the nature of *innovation* better equips commercialization staff to facilitate its acceleration and anticipate the likely impacts of deploying novel CLC crops and systems. Similar to technology transfer and adoption, innovation has been a major topic of inquiry in economics and business since the early 20th century. Joseph Schumpeter –well-known for his consideration of 'creative destruction'– was concerned with the role of innovation as spurring major transitions in economic development and society at large. Perez (2010) summarizes, "Schumpeter strongly distinguished innovation, seen as the commercial introduction of a new product or a 'new combination,' from invention, which belongs to the realm of science and technology," and further distinguishing that, "The meaningful space in which technical change in society needs to be studied, therefore, is that of innovation, at the convergence of technology, the economy, and the socio-institutional context." Innovation can occur in business structure, products, processes, branding, and other dimensions. Common characteristics of innovation include being interactive, located, a learning and integrative process, often or largely non-technical, social, cultural, and based on creative destruction (Romanowski, 2019). This distinction between invention and innovation highlights the gulf between the scientific development of a perennial grass into a grain crop (invention) and all that is required in physical processing, product, business, and market development, marketing, and effectively positioning this package in the socio-institutional environment to meet evolving consumer, industry, and public priorities (innovation). This gray space between invention and innovation is where commercialization staff call home. Crucially, commercialization staff are primarily facilitators of others across the food and agricultural system catalyzing innovation around novel CLC crops. With any success, the transition to CLC will be characterized by innovation, entrepreneurship, and creativity among actors outside the research enterprise that will take novel CLC technologies on-farm, to the market, into policy arenas, and to-scale.

In the latter 20th and early 21st centuries, the field of neo-Schumpeterian economics generated rich insights into the nature of innovation processes. Its researchers identified the ways in which entrepreneurship and innovation create dynamic and uncertain environments in which, "the set of possibilities itself is subject to unexpected change," through which, "more complex modes of behavior which include 'potential surprises' become relevant." (Hanusch and Pyka, 2007). The field readily recognizes that the most visible type of innovation, that of technological innovation and change, is intimately bound up with organizational, institutional, and social innovation. Innovations tend to, "not only modify the business space, but also the institutional context and even the culture in which they occur" (Perez, 2010). This is particularly relevant to the innovations in policy needed for CLC crops, which span notions of productive agriculture and agricultural conservation, and the cultural change needed for perennializing 10,000 years of heretofore annual row crop agriculture.

Neo-Schumpeterians assert that the process of introducing innovations is decidedly nonlinear, proposing logistic (S-curve) "innovation rhythms" in which initial slow innovation reflects interlinked actors' iterative learning processes. The emergence of dominant designs lead to cascading changes and scaling, followed by a slow-down at an innovation's maturation and saturation. Moreover, these innovation rhythms develop one or more "trajectories" in large possibility spaces in which uses, standards, relative costs, accompanying practices, and market acceptance are defined. These trajectories are defined as incremental innovations that build on original radical innovations. These concepts provide insight into the fundamental uncertainties and rhythms of dynamic change across modes of innovation that are likely to occur as a novel CLC crop with transformative potential makes headway. While much focus in the Kernza and CLC community focuses on the scientific development of new and improved crops and associated knowledge, those concerned with innovation might put their locus of study on the ways in which these inventions and new knowledge find footing in the world in the form of viable products, businesses, and new value propositions, and how that innovation in turn informs institutional, public, firm, and consumer priorities, assumptions, and possibilities.

Innovation management can influence firms' and institutions' competitiveness and success. Within the context of TLI and UMN, innovation management may be understood as the wide range of activities that occur at the intersection of portfolio-level and crop-specific interfacing between basic researchers, commercialization staff, and novel CLC crop early adopters and stakeholders. Seven common dimensions of innovation management include inputs management, knowledge management, innovation strategy, organizational culture and structure, portfolio management, project management, and commercialization (Adams et al., 2006). Innovation management models have been conceived as technology (push), market pull, coupling, integrated, networking, open innovation, and open innovator (Romanowski, 2019). Kline's (1986) "chain-linked" integrated model reflects the iterative, dialectical, almost folding nature of innovation management in which CLC commercialization staff cross-walk the research and commercial environment with timely information, new knowledge, opportunities, and resources.

Innovation systems are, "interlinked sets of people, processes, assets, and social institutions that enable the introduction and scaling of new ideas, products, services, and solutions capable of facilitating impact" (Thiele et al., 2022). The notion of innovation systems coupled with regional sciences developed the concept of regional innovation systems (López-Rubio et al., 2020), which focus on the interdependencies between regionally co-located firms, human capital, context, institutions, networks, and other inter-relationships and the potential positive externalities thereof. The regional innovation systems lens suggests that the entities developing novel CLC crops may benefit from strategically deploying such crops in concentrated geographic areas as a means of reducing transaction costs, finding efficiencies, and spurring innovation.

In practice, innovation and related concepts are ever-present in the process of commercializing novel CLC crops. The work is full of newness– new observations, problems, challenges, work-arounds, uses, products, value propositions, partnerships, policies, and cascading impacts. The enthusiasm and drive of entrepreneurs on-farm, in grain processing facilities, kitchens, breweries, bakeries, and food companies are critical forces needed to transform CLC inventions into CLC innovations. Shepherding a fundamentally innovative process, CLC commercialization staff are constantly instigating, fostering, communicating, and adapting to innovation in their work. A focus on innovation requires paying close attention to the details of nuanced processes such as grain harvest, post-harvest management, seed cleaning and processing, milling, malting, brewing, baking, and marketing. Experimentation, iteration, and sometimes accidents lead to valuable insights and innovations. Such processes often create closely-guarded innovations that provide an edge or differentiation to actors in the marketplace whereas others are shared widely, creating spillover effects that catalyze advancement of the wider enterprise. Rarely are commercialization staff the ones developing these innovations, but often they are the actors, communicating, and adapting CLC communities to the impacts of innovation.

The innovation process surrounding Kernza perennial grain reflects many of the principles of neo-Schumpterian economics. For example, the actions of Kernza growers, entrepreneurs, and buyers regularly invoke dynamic and uncertain pathways for Kernza's role in the market as well as the organizational, institutional, and social environments in which this novel grain and its formative value proposition is taking root. Debates during the price discovery phase have highlighted varying innovation trajectories for Kernza as, alternatively, a high-value non-commodity grain that substantially supports growers and rural communities in the transition to organic and regenerative organic agriculture; a widely-consumed and modestly more affordable climate-smart food used at higher inclusion rates in products; or a scalable market-driven tool for water quality protection. None of these three trajectories are mutually-exclusive, but all have implications for involved actors. Similarly, start-up businesses focused on Kernza are closely considering strategies for relationship development with customers, customer engagement in product design, grain-based product bundles, and innovations intended to circumvent relatively non-transparent, extractive grocery distribution supply chains. State and federal policymakers are recognizing a number of ways public programs and investments may require reform and innovation to account for perennial grains and other novel market-based CLC crops. At the cultural level, Kernza entrepreneurs, consumers, and champions are beginning to ask what a perennial grain economy and society might look like. Where such ideas lead no one quite yet knows. All such examples indicate shifting innovation trajectories, possibility sets, and technical innovations with the potential to domino into social and cultural innovations. These developments accord with contemporary understanding of innovation as a multi-faceted process in which technical, social, cultural and organizational innovations cohere in "new effective combinations" that enable technical innovations to achieve scale and societal impact (Leeuwis and Aarts, 2011; Herrero et al., 2020).

CLC commercialization and stewardship staff's role in this process is to observe and articulate emerging innovation rhythms and trajectories, mirroring back to stakeholders enmeshed in the innovation process the larger arc, potential pathways, and their dynamic effects on the enterprise as a whole. Between 2019 and 2022 this has been accomplished for Kernza through detailed narrative documents provided by UMN FGI written for Kernza stakeholders at large, as well as integrated call series and webinars hosted by these staff that, through their design and execution tell the story of Kernza's emerging innovation trajectories in its stakeholders own voices. Commercialization staff observe if not anticipate inflection points in innovation rhythms, messaging to stakeholders and the public as appropriate. Bending the arc on these trajectories may be important for retention of critical partners, staving off consolidation of power and resources by single actors or supply chain segments, or otherwise maintaining the pursuit of public benefits of the novel CLC crop.

Kernza commercialization staff must construct practical innovation management strategies between crop R&D teams, commercial interests, and other stakeholders to communicate the latest learnings, needs, and challenges in multiple directions. Examples in Kernza from 2019–2022 include close collaboration with growers, processors, and researchers to document and communicate various harvest methods, mycotoxin levels, the impact of processing (dehulling) on mycotoxin levels, cleanout rates, and test weights. These early learnings were generated through informal collaboration over several years by early adopter growers, start-up partners, and researchers seeking to set a common baseline understanding of working with this new novel CLC crop. Winter call series and events convening growers, researchers, value chain actors, policymakers, and community partners are a key programmatic mechanism for innovation management. In 2021 and 2022, the grower-researcher call series, designed primarily for technology transfer and adoption with growers, expanded to a strategic integrated presentation on the status of Kernza to a wider range of Kernza stakeholders. What was previously self-directed by market actors through piecemeal informal collaboration is coalescing into systematized innovation management processes. For example, in the ensuing years, UMN Kernza breeders, food scientists, and commercialization staff have designed a project to streamline collaboration with Kernza growers, agricultural utilization partners, processors, and food companies to systematically assess needed alterations to harvesting, seed cleaning, processing, milling, and sifting in response to germplasm improvement. Similar to the way growers steward their fields and researchers steward their labs, these are examples of commercialization staff's role stewarding the innovation process. Finally, the literature on innovation management suggests that agricultural innovation platforms developing novel CLC crops have significant room to grow in articulating and implementing explicit innovation management strategies (Biggs et al., 2012).

The Upper Midwestern US, and specifically Minnesota, stands out to Kernza commercialization staff as an active regional innovation system for Kernza perennial grain. It is characterized by relatively tight geographic presence of many if not all of the types of actors necessitated to innovate in grain systems: breeders, agronomists, natural resource scientists, food scientists, growers, farmer groups and agricultural nonprofits, processors, millers, brewers, food companies of all scales, funders, investors, state support, engaged policymakers, consumers, and communities. This regional innovation ecosystem is no accident, it has been intentionally cultivated over several decades by institutional actors at UMN including the Forever Green Initiative, Green Lands Blue Waters, the Regional Sustainable Development Partnerships, the Minnesota Institute for Sustainable Agriculture, not to mention the well-known presence of strong social capital and civic engagement in the state of Minnesota. While Minnesota may not have the greatest climatic comparative advantage for producing Kernza perennial grain, comparative success there warrants subsequent research on the degree to which, for example, strong bridging social capital may greatly accelerate CLC crop innovation. Cultivating and maintaining a regional innovation system around novel CLC crops requires constant support from commercialization staff. For Kernza between 2019 and 2022, this has included annual strategic communications to frame regional success, progress, bottlenecks, and priorities; regular communication and coordination to support key partnerships like an emerging cooperative; onboarding and incorporation of new entrepreneurial energy; and transparency, accountability, and self-awareness to steward the system as a whole rather than choosing favored actors.

The benefits of a regional innovation system are highlighted by the experience of Kernza adoption in Wisconsin, where local commercialization intermediaries identify the lack of such a system. Wisconsin neighbors Minnesota and because of similar latitude, topography, and soil history, agriculture is generally deemed quite similar between the two states. However, Kernza adoption and production has diverged considerably among Minnesota and Wisconsin. While Minnesota is currently home to nearly 1,300 acres of Kernza situated on over 40 farms, just three growers are actively growing Kernza in Wisconsin on a total of just over 200 acres. Despite Wisconsin having a perennial crops program, university researchers with a history of collaboration with TLI, experience in sustainability innovation in farm cooperatives and organic production, and a relatively high degree of farm diversity compared to other states, this has not yet been enough to spur significant Kernza adoption.

Wisconsin commercialization staff feel that Wisconsin has thus far lacked the institutional commitment, civic and public support, and investment to support a regional innovation system. In comparison, Minnesota's state and other investments stimulated a wide variety of projects and partnering organizations, including university-municipal partnerships to deploy Kernza for its environmental benefits, university-farmer collaborations, civic-sector support, and private business startups to support commercialization efforts. The comparable lack of funding in Wisconsin stymied Kernza's pre-adoption pipeline, as university researchers were restricted to relying on federal grant programs to support agronomic and extension work. Even fewer resources are available to support Kernza's integration into business supply chains. Wisconsin's smaller grower community has identified significant challenges accessing the seed supply and post-harvest processing options predominantly located in or adjacent to Minnesota. A takeaway lesson has been that investing in post-harvest processing, infrastructure, and grain handling recommendations, and building human capital and desire to refine grain post-harvest, is just as important as developing agronomic research and production guidelines, which is often where investment is directed early on with new crops. This results in imperfect options: risk holding grain until localized facilities emerge or erode profit by shipping longer distances. The relative lack of grower adoption has created compounding challenges, such as insufficient grain volume to interest potential cleaners, processors, and end users to perform tests with Kernza, ultimately impacting Wisconsin Kernza sales. In the absence of state support, growers assume the entire risk out of a devotion to environmental protection and investment in improving the impact of their farming operations. The dedication of these individuals, like those in MN, cannot be overstated.

In sum, Wisconsin serves as an example of a region where enthusiasm from some researchers, growers, supply chain actors and advocates has lacked sufficient support to develop a regional innovation system, hindering the regional adoption and scaling of this novel CLC crop. By comparison, Minnesota demonstrates that well-supported, concentrated, dynamic innovation systems can accelerate commercial development, reduce transaction costs, and de-risk adoption, and that such activity provides positive externalities for wider actors.

2.3. Intermediaries and innovation brokers

CLC commercialization staff can be understood to operate as intermediaries in sustainable agriculture innovation systems. The concept of intermediaries arises from a growing body of literature that highlights the particular importance of intermediary actors in facilitating transitions to more sustainable systems (Moss, 2009; Steyaert et al., 2016; Mignon and Kanda, 2018; Kivimaa et al., 2020). Intermediaries are thought to positively influence sustainability initiatives by linking diverse entities and their related resources and skills, creating new collaborations across niche technologies like Kernza, linking technologies to markets, and generally creating momentum for system change (Kivimaa et al., 2019). Others have underscored the importance of intermediaries in brokering and transferring knowledge, aggregating lessons, and mobilizing resources (Klerkx and Leeuwis, 2009; Goodrich et al., 2020; Kanda et al., 2020). Despite the various roles ascribed to them across the literature, intermediaries are near-unanimously defined by their ability to span boundaries (Bergek, 2020), be it across actors, networks, institutions, spatial extents, or scales.

There is a general understanding that a full ecology of intermediaries, from those that operate on a systemic policy level to those who support particular niche technologies, is needed to support a transition process and that the network of intermediaries shifts over time. Given the emergent and uncertain change processes in scaling new technologies and systems, intermediaries can act in conflicting roles barring sufficient coordination (Kanda et al., 2020). The mounting body of evidence suggests that intermediaries and their coordination may play a critical role in a transition to CLC agriculture. Additionally, given transition intermediaries' normative orientation toward change, they can never be fully neutral actors (Moss, 2009; Steyaert et al., 2016), and as such, intermediaries must recognize their power to be both a guide and a gatekeeper to various entities (Sovacool et al., 2020).

More specifically, Kernza commercialization staff often operate as innovation brokers, a particular type of intermediary that, "from a relatively impartial third-party position, purposefully catalyze innovation through bringing together actors and facilitating their interaction" (Klerkx and Gildemacher, 2012). These actors institutionalize facilitation of innovation systems for system-level impact, expanding the nature of extension activities from one-to-one to many-to-many. Common functions of these actors are to analyze context, articulate demand, compose networks, and facilitate interaction. A typology of innovation brokers spans innovation consultants working with individual or groups of agricultural producers and enterprises, peer network brokers, research and innovation councils, and several others. The potential impact of innovation brokers is significant, but their 'ghost in the machine' nature often leaves their role poorly understood by funders and innovation system stakeholders.

Brokering innovation is decidedly different from other key systemic intermediary activities of commercialization staff such as navigating important but largely technocratic tweaks to policy regimes to better incorporate novel CLC crops. It often involves brokering resources–physical, financial, relationships, information, or otherwise–to spur commercial activity and entrepreneurship, indicating that theories of intermediation have evolved from the seminal field of technology transfer. For example, an early reserve of grain from state-supported water quality trials was, not by accident, provided by Kernza innovation brokers as 'start-up grain' to a team of Kernza entrepreneurs, which helped them launch a business that continues to be on the forefront of Kernza innovation. This entailed discernment of potential system-level impact, and targeted brokering of physical assets. Dozens of such small and large examples exist in which commercialization staff benevolently broker interests, skills, expertise, information, resources, and access to novel crop technologies with disparate actors. A number of activities previously discussed in the technology transfer section and otherwise could, when taken together with considerations of innovation processes, be recast as workflows in the milieu of innovation brokering.

2.4. Legitimacy

For new crops and cropping systems, developing authoritative knowledge and building systems for its acceptance is an arduous process. Montenegro de Wit and Iles (2016) discuss how, even after decades of concerted and organized effort, the organic movement has attained only 'thin legitimacy' based primarily on market demand and policy intervention. Both of these are important, but for new crop adoption to happen on a temporal and spatial scale that can catalyze meaningful change, legitimacy must be expanded and built on additional, credible, and authoritative processes, dubbed 'thick legitimacy'. Some of these processes include drawing in consumers and companies, enacting government rules that recognize or support the transfer and adoption of new crops and cropping systems, increasing scientific interest and the number and types of research that are happening, and attracting farmers to the new system (*ibid*).

In practice, commercialization and stewardship staff can bend the arc of legitimacy, but rarely are its primary determinants. Legitimacy is achieved first and foremost through the viability of a technology to perform on farms and in products, and its ability to achieve given societal outcomes. The series of actors needed to adopt, prove, promote, plant, and purchase the novel CLC crop are integral to achieving legitimacy. While somewhat more removed from the direct enterprise, policymakers and agencies are essential actors in advancing or hindering novel CLC crop legitimacy. As discussed below with regard to the Multi-Level Perspective (MLP), achieving legitimacy is contingent on the times as well as the technology. For example, Kernza is much better positioned to achieve legitimacy in the rise of the regenerative agriculture movement and age of climate instability than it would have been 50 years prior in a yield-centric paradigm.

Commercialization and stewardship staff working to build legitimacy for Kernza have acted to stabilize areas in which various actors have made inroads to authority. In the scientific arena, we have worked to create spaces for scientific sharing and collaboration, including organizing and hosting two international Kernza meetings in collaboration with other scientists from 2019–2022. These spaces build community, but also present criticisms, identify missing areas of research, and build strategies for addressing these. Additionally, they are a space to discuss civic engagement, policy and advocacy needs, and create plans to obtain funding.

From these Kernza discussions, it is clear that two critical areas of research are social sustainability and ecosystem service payments for farmers. The addition of social sustainability research is critical to advancing Kernza in the marketplace. One definition of social sustainability is when, "people are not subject to conditions that systematically undermine their capacity to meet their needs" (Missimer et al., 2017). New research on how and whether Kernza supply chain actors are engaging in socially sustainable practices is ongoing. The aforementioned Forever Green EECO Implementation Program is an example of legitimacy being built for both Kernza perennial grain and ecosystem service payments via state government entities endorsing and funding such programs. Additionally, Kernza has seen recent successes as perennial grains have been added to the NRCS's Conservation Stewardship Program Enhancements for 2021 and the Farm Service Agency has begun to allow growers to certify IWG as a grain crop for data collection and whole farm insurance purposes, opening a window to further support by USDA programs and continue building legitimacy.

Kernza commercialization and stewardship staff have made inroads in developing civic legitimacy by leading the early development of a Kernza Stewards Alliance (KSA) composed of supply chain stakeholders, from growers to food product manufacturers, that is to some extent modeled on other commodity organizations designed to promote products. However, unlike other commodity organizations, the KSA is moving toward a steward-owned model that will create mechanisms to shift power out of the hands of institutions, such as TLI and UMN, and into the hands of supply chain stakeholders by transferring ownership and governance of the Kernza trademark to its licensees. UMN and TLI will maintain a voice through a perpetual purpose trust, a body committed to the long-term benefits of Kernza perennial grain. The engagement, involvement, and enthusiasm of these actors for this process and its goals is a demonstration of legitimacy. However, the lack of precedent for the establishment of this complex entity provides a clear need for additional legal clarity and legitimacy, indicating that various modes of legitimacy are intimately bound up with one another.

2.5. Multi-level perspective and sustainability transitions

Geels's Multi-Level perspective is a critical framework used to understand socio-technical transitions and sustainability transformations and thus provides an important basis to understand the commercialization, adoption, and scaling of Kernza. The MLP claims that there are three critical levels in a socio-technical transition effort: niches, regimes, and a landscape (Geels, 2002; Geels, 2019). The MLP posits that stable regimes like industrial agriculture are notoriously hard to disrupt, however niche innovations that operate outside of the dominant culture have the potential to destabilize regimes if sufficient bottom-up momentum is met with top-down pressure from the landscape level. Landscape level pressure can be endogenous (e.g., major policy changes) or exogenous (e.g., pandemic, climate change). Thus, the MLP suggests that Kernza, as a niche, will need concerted alignment with the regime and landscape to open a window of opportunity to effectively establish itself. Additionally, this theory offers a four-phase understanding of a transition, demarcated into: experimentation, stabilization, diffusion and disruption, and anchoring or institutionalization; which can orient actors in transition efforts that often span multiple decades (Geels, 2019). The MLP has proved formative to studies of sustainability transitions (Köhler et al., 2019) and although it has been applied to agri-food systems, it is based primarily in a socio-technical systems framework that may not best account for socio-ecological systems, here being the ecological realities inherent to agriculture, and the unique market and decision-making structures of agricultural systems (Duru et al., 2015; El Bilali, 2020). It may prove best to engage with the MLP critically in the hopes of augmenting the framework to better describe transitions in an agricultural context.

In practice, MLP highlights that the viability of novel CLC crops is contingent on landscape changes and regime acceptability in addition to technological readiness. CLC commercialization staff must therefore focus on the regime and landscape factors as well as shepherding the niche solution. More specifically, they must situate themselves as competent interpreters and instigators of niche-regime, regime-landcape, and niche-landscape interactions, a role described as systemic intermediary above (e.g., Kivimaa et al., 2019).

Engagement of incumbent regime actors and ideas is constant, detailed, and necessary. For example, commercialization staff often lead or support methodical work to make "lateral," technocratic inroads into highly structured agency and policy mechanisms needed to either legitimize or bring online support for a novel CLC crop or system. Several examples include working closely with USDA Farm Service Agency to allow growers to certify their IWG acres for grain production, incorporating IWG into agricultural conservation practices and incentive programs. With the first official commercial variety release in 2019 and less than 5,000 acres in production, Kernza is in an early phase of developing these support mechanisms. Achieving these milestones also often requires development of associated tools such as enterprise budgets, economic models, harvest reports, and contributing to peer-reviewed literature. As often as commercialization staff may talk to prospective growers or end-users, they are equally as likely to engage Soil Water Conservation Districts and other state agency staff. They may also engage legislators, peer organizations and institutes, academics.

Finally, commercialization staff and many other Kernza stakeholders invest significant time incorporating Kernza into key cultural events and institutions such as state and county fairs, FarmFests, museums, arboretums, school programming, and more. Since the mid-2010's, Kernza's presence being served by a farm-to-table restaurant in partnership with a grower advocacy group was a key regime inroad to Minnesota's culinary and public conversation. In

Minnesota, Kernza is also now growing at both a premier science museum, with accompanying exhibit on CLC agriculture in development, as well as a premier arboretum and onsite at several schools, associated with Future Farmers of America (FFA) programs. While adjacent or parallel to core activities of developing commercial production, supply chains, and markets for Kernza, these activities require substantial interfacing with commercialization staff and build further regime acceptance.

2.6. Scaling readiness

Given overwhelming potential activities and often limited instruction, it is helpful to couch tactical commercialization actions in broader, strategic context. A recently developed framework that supports this is scaling readiness. It encompasses both evaluative measures that assess the readiness and use of an innovation or innovation package (Sartas et al., 2020) and methodologies or processes that result in adoption, niche and regime change, and have implications for legitimacy both in terms of scaling out and scaling up (Wigboldus and Leeuwis, 2013). Alternatively put, scaling readiness provides innovation brokers with a framework for understanding, visualizing, and strategizing around the maturity of core innovations, and the many accompanying innovations needed for its success. In the context of CLC and Kernza, the framing of innovation packages used by Sartas et al. (2020) is particularly useful. In this frame, the scaling of an individual innovation (e.g., Kernza perennial grain) requires the scaling of related innovations such as new varieties, seed handling and distribution best practices, harvest methods, processing infrastructure and methods, on-farm storage solutions, markets, marketing strategies, business structures, and policy strategies. This framework of scaling readiness further validates and operationalizes the aforementioned and accompanying notions and necessarily interlinked technical, economic, social, cultural, policy, and institutional innovations (Leeuwis and Aarts, 2011; Meynard et al., 2017; Herrero et al., 2020).

The scaling readiness framework has helped Kernza commercialization staff navigate their complex work of tracking the development of innovation packages and directing resources to building out components lacking in readiness or use. Specifically, the framework was used to identity an innovation system components lacking in readiness, seed supply, which created a systemic bottlenecks. The identification of the seed supply bottleneck informed intensive efforts to alleviate Kernza seed shortages and improve quality in the seed supply, as well as expand markets for Kernza perennial grain. An excellent subsequent exercise would be to more explicitly map Kernza's innovation package by readiness and use utilizing the scaling readiness methodology (Sartas et al., 2020; Schut et al., 2022) in partnership with Kernza stakeholders to identify key bottlenecks worthy of attention, support, and investment.

In particular, challenging notions of context independent scaling is important in CLC agriculture where social complexity and technical complexity are both great. Novel CLC crops are not substituting one crop or variety for another or one management practice for another. Novel CLC crops and their stakeholders are creating new systems of growing, managing, processing, distributing, creating, and valuing food. This requires an innovation package that is adaptable based on physical production and processing technologies, product development, policy support, consumer awareness and values, and institutional mechanisms.

3. Discussion

This investigation of relevant fields in the light of our practice narratives suggests that multiple related processes are inherent in CLC commercialization staff's work such as technology transfer, intermediating between niche technologies and regime actors, innovation management at the institutional portfolio level, innovation brokering of specific novel CLC technologies across innovation systems, and building legitimacy within slowly transitioning regimes. In practice, these processes may be occurring all at once (e.g., in the same room) via capacity-delimited programming. This suggests that the multiple functions of commercialization roles need to be integrated in practice with adaptive, multifunctional, nimble staffing.

In the course of this work, CLC commercialization staff often find themselves confronted with the need to make specific choices that may shape innovation trajectories in particular directions or, alternatively, find themselves tasked with intervening in attempted plays to change innovation trajectories that significantly diverge with institutional or otherwise broadly shared narratives and values. Acting as a steward of this process rather than a gatekeeper that hinders innovation and regime transformation is a delicate dance.

Notably, the various activities of novel CLC crop commercialization staff are often highly disparate, and in some cases greatly so. For example, physically transferring a novel perennial grain crop to spur entrepreneurship and innovation is distinct from navigating local, state, and federal institutional and policy environments to generate CLC portfolio-level support at the regime level. The CLC crop or cropping system may be a throughline but otherwise the actors, goals, strategies, and cultures of such processes can vary wildly. Among all concepts reviewed, the intense experience of CLC commercialization staff members is perhaps best characterized as being simultaneous innovation brokers of novel CLC crops to their stakeholders as well as transition intermediaries navigating and surmounting the mazes, riddles, and roadblocks of regimes.

Since these many activities closely relate to but function outside the process of developing new technologies (i.e., crop varieties) and knowledge (i.e., agronomic best management practices), the scale and nature of support needed to move novel CLC crops from invention to innovation to scale across landscapes and markets may not be immediately apparent. However, the practice narratives suggest the need for coordinated action to shape and advance the adoption and scaling of novel CLC crops. Critically, the design principles of such coordinated action need to be based on responsiveness, flexibility, adaptation, and dynamism.

These concepts and practice narratives support development of a practical theory for bridging new CLC technologies into the food and agricultural sector and society at large. Layered and nuanced intermediation theories can obscure the critical, practical need for a clear technology transfer strategy with defined actors and adequate support. Similarly, institutional actors, intermediaries, and policymakers may wax poetic about innovation without providing the practical financial and staffing support to meet the significant needs of entrepreneurs to wrap their arms and minds around novel CLC crops and develop go-to-market strategies. Overall, these fields of literature suggest that a robust if decentralized architecture of intermediation must be constructed and sustained to facilitate technology transfer of novel CLC crops, the innovation likely induced thereof, CLC crop enterprise scaling, and niche-regime-landscape interaction and transformation. Such architecture boosts the chances that CLC inventions more rapidly translate to CLC adoption, innovation, scaling, and impact.

Several important caveats are in order. First, while attempting to crystallize early learnings, commercialization staff still consider Kernza to be in its early phase of commercial development and the best practices for facilitating novel CLC crop commercialization are emergent. Second, these staff readily acknowledge that the basic research and development work on CLC crops such as Kernza precedes and continues alongside their commercial development. Long-term, continued advancements in breeding, agronomic best management, clear understanding of environmental benefits, and robust food science are key factors in Kernza perennial grain's commercial viability, and this will likely hold for most other perennial grains and oilseeds. Without significant and sustained investment in developing and improving CLC crops and cropping systems, much of what's discussed in this article is moot. At the same time, development of a new crop without investment in supply chain and markets fails to deliver the novel CLC crop's intended impact. Also, the independent actions of private actors in the market often precede or supersede the actions and relevance of commercialization staff, and indeed are necessary for novel CLC crops to move forward. In a best case scenario, commercialization staff function as integral parts of the CLC crop development enterprise, serving as stewards of the innovation process that sit between these researchers and private actors to move novel CLC crops from the lab to the field and market.

4. Conclusion

Taken together, the concepts reviewed and practice narratives indicate that a 'practical theory' of novel CLC crop commercialization:

- Is technology (crop or system) specific, and spanning many dimensions thereof
- Is built on a robust research and development platform for said technology
- Requires collaboration across disciplines, sectors, and the entire value chain
- Is likely, at least at first, regionally situated in specific geographic, social, cultural, environmental, economic, and institutional conditions
- Must understand, account for, support, and navigate multifaceted innovation processes
- Requires effective innovation management strategies at the institutional or systemic level
- Is aided by the existence and further fomenting of regional innovation systems that offer appropriate degrees of protection, risk, and dynamic interplay between stakeholders
- Requires well-supported teams of innovation brokers and other intermediaries to interface with R&D efforts and myriad novel CLC crop stakeholders
- Must be attuned to incumbent landscape pressures, regime arrangements, sustainability transitions underway therein, and the need to consistently build legitimacy for the novel CLC crop or system within actively changing regimes
- Demands systems-level understanding of core and accompanying innovations, with strategic focus on addressing the most underdeveloped elements of innovation packages

For all the described activities, nationwide Kernza commercialization staff has consisted of a small group that notably perform similar functions for institutional portfolios of 6–10 novel or improved CLC crops and systems in addition to Kernza, resulting in thin capacity for any one crop or function. Marshaling adequate resources in the form of multiple well-qualified people, associated facilities, and institutional support prior to or in the earliest days of novel CLC crop commercialization is crucial yet challenging. Yet again, the endemic 'chicken-egg' problem in new crop commercialization may strike in which such investments are too hard to justify, given the many and good alternative uses. The innovation broker role may often find formal or informal alignment with existing institutional roles, which may come with synergistic benefits as well as drawbacks. Our conceptual review and practice narratives highlight the abundant support needed and value of investing in innovation broker capacities.

Moving forward, this article suggests that novel CLC crop commercialization activities already do and will continue to present a wealth of case studies from which to refine a practical theory of novel CLC crop commercialization. Recognizing major differences across regional innovation systems and CLC crops in their portfolios, CLC commercialization staff have begun constructing developmental frameworks for innovation packages and commercialization model typologies. Further research is warranted to explicate these ideas. Similarly, several crucial concepts omitted from this initial paper include concepts for balancing economic, environmental, and social values in the commercialization process, such as sustainable commercialization, as well as governance of novel CLC cropping systems. This suggests that novel CLC crop commercialization is not only a robust field of practice but also fertile ground for critical applied research on practical methodologies and frameworks that can support a wide range of actors to drive a rapid transition toward continuous living cover agriculture at scale.

Author contributions

CCu conceived the project, conducted literature review, and was the primary manuscript writer and editor. SS contributed to the early commercialization narrative and figure creation. TP, NT, and CCa contributed to writing practitioner narratives, AR helped refine the scope, contributed to the early commercialization narrative, and edited. TC contributed to literature review and editing. NJ helped with theoretical framing and scope refinement. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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

Publisher's note

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