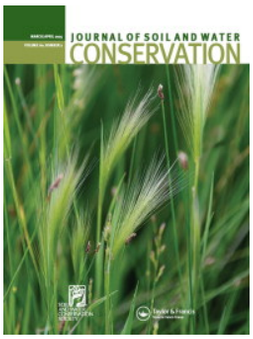

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Our daily bread in the Heartland: Understanding and leveraging diversification to small grains in corn and soybean systems

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ABSTRACT

Incorporating small grains (cereal crops with small kernels such as barley [*Hordeum vulgare* L.], oats [*Avena sativa* L.], rye [*Secale cereale* L.], and wheat [*Triticum aestivum* L.]) in corn (*Zea mays* L.) and soybean (*Glycine max* [L.] Merr.) rotations in the Upper Midwest contributes to regional food systems resilience while improving ecological health and providing economic value to the farmer. Yet, few farmers in the region grow small grains, and simplified production of corn and soybeans dominates the landscape. This research identifies the barriers farmers face to growing small grains and the factors that have helped some to be successful in their small grain operations. We do so through a survey of 406 row crop farmers and interviews and focus groups with 38 farmers and nonfarming agri-food professionals who engage with or support grain production throughout the states of Iowa, Illinois, Minnesota, and Wisconsin. A combination of farmer-reported survey results, correlation network analysis, and findings from focus groups and interviews showed that a range of biophysical, structural, and operational factors influence why farmers do or do not incorporate small grains in their operations. We found that the availability of markets, market prices, regional growing conditions, and added management are primary barriers to small grain production on row crop farms. Access to equipment, improved small grain varieties, and the timing of planting and harvesting can be both drivers and barriers, depending on the farmer. Cost share programs, livestock, organic certification, the system benefits of small grains, and the synergies between small grains and cover crops are found to be drivers of production. Crop insurance and revenue supports (Price Loss Coverage, Agriculture Risk Coverage, and Marketing Assistance Loans program) for small grains, availability of neighbors growing small grains, availability of technical assistance for small grains, and access to a loan for small grain production were less important relative to the aforementioned barriers and drivers. To enable strong agricultural markets and support farmers to produce small grains, it will be important for educators and decision-makers in agriculture and the food system to (1) invest in market development, on- and off-farm infrastructure, and improved varieties; (2) level the playing field with corn and soybeans in terms of subsidies and supply mandates; and (3) leverage the drivers of existing small grain acreage—certified organic production, the integration of crops and livestock, systems thinking, and cover crop use.

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INTRODUCTION

In the US Upper Midwest, an area dominated by corn (*Zea mays* L.) and soybean (*Glycine max* [L.] Merr.) production, adding small grains to crop rotations provides a unique opportunity to improve the economic and ecological resilience of farms while building local food systems. Increasing research shows that rotating small grains, or cereal crops with small kernels such as barley (*Hordeum vulgare* L.), oats (*Avena sativa* L.), rye (*Secale cereale* L.), and wheat (*Triticum aestivum* L.), with corn and soybeans can improve the yields of corn and soybeans and increase combined net returns of the rotation (Bowles et al. 2020; Davis et al. 2012; Gaudin et al. 2015; Janovicek et al. 2021), and at the same time enhance soil health and water quality. These benefits occur through several mechanisms. As cool season crops, small grains increase surface cover and keep roots in the ground throughout more

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of the year, improving soil structure (Janovicek et al. 2021) and soil water storage (Basche et al. 2016). Improved soil structure and water storage increases nutrient and sediment retention, thereby reducing soil erosion and leaching, which in turn reduces nitrogen (N) and phosphorus (P) losses and freshwater toxicity (Hunt, Hill, and Liebman 2017, 2019). Farmers' bottom line and the environment also benefit from the natural disruption of cycles of weeds, pests, and diseases that diverse rotations bring by reducing the use of chemical pesticides and herbicides (Davis et al. 2012).

Beyond improved ecological and agronomic conditions, small grains can diversify income and contribute a local source of grains that have been largely missing from the basket of local foods available to consumers. As a cash crop with the potential to sell into local or regional high-value food-grade markets, small grains incorporated into simplified systems offer greater enterprise resilience in addition to on-farm resilience (Carlisle 2014). Spurred by a growing interest in high quality flours (AGC 2024a), emerging artisanal brewing and distilling sectors (AGC 2024a), and supply chain disruptions from the COVID-19 pandemic (Wu 2020) and increasingly supported by local policies (Grow NYC 2023; Washington 2020), markets for local and regional small grains are emerging in the United States (Baker and Russell 2017; Forrest and Wiek 2021).

Despite their environmental benefits and growing economic promise, most farmers in the region do not plant small grains, and as of 2023, corn and soybeans comprised 90% of field crop acres in the Upper Midwestern states of Iowa, Illinois, Minnesota, and Wisconsin (USDA NASS 2023). The simplified production of corn and soybeans on the vast majority of farmland in the region has led to significant social and ecological repercussions including soil erosion (Thaler, Larsen, and Yu 2021), ground and surface water pollution (Rabalais and Turner 2019), and loss of above- and belowground biodiversity (Perfecto 2009; Rosenberg et al. 2019; Vandermeer 2018).

Integrating small grains into corn and soybean systems is one promising way to improve the diversity and resilience of the Upper Midwestern agricultural landscape. More work is needed to understand how to support their adoption by farmers. To this end, we used a mixed method approach including survey, interview, and focus group data to understand the following research questions: (1) what are the most important factors determining the adoption of small grains? and (2) what opportunities exist to increase future small grain production? We begin by discussing the history of small grains in the Upper Midwest and the existing literature on the barriers to and drivers of adoption of small grains. We then explain the conceptual framework driving the study design and analysis, followed by a description of the methods used, including quantitative and qualitative data collection and analysis. Next, we present the results by method, and then discuss the results integrated across all methods by determining factor. We conclude with implications and recommendations for increasing small grain production in the region.

The decline of small grains in the Upper Midwest

Farmers in the Upper Midwest historically grew crops in a rotation of corn, small grains, and hay and raised a range of types of livestock (Hart 1986). Over the last century, the combination of the biophysical characteristics of crops, regional growing conditions, research and development, global markets, and state support for the modernization and efficiencies of agriculture propelled US agriculture toward the simplified production of two crops: corn and soybeans (Blesh and Galt 2017; Friedma and McMichael 1989; Ilbery and Bowler 1998). Beginning in the 1930s, technological developments encouraged intensification and specialization through mechanization, synthetic inputs, and improved variety seed (Lighthall and Roberts 1995; Ward 1993). As production costs increased, farms grew larger and more specialized to capture greater economies of scale to pay for more expensive equipment and inputs. Synthetic fertilizers and pesticides replaced extended crop rotations traditionally used to maintain soil health and break up cycles of pests, weeds, and disease (Buttel 2006; Friedma and McMichael 1989). The availability of synthetic fertilizers also meant that farmers no longer needed livestock manure to maintain soil fertility, spurring, in part, the decoupling of crop and livestock production (Sulc and Tracy 2007).

The inherent characteristics and versatility of corn and soybeans and conducive regional growing conditions made them the principal crops for specialization in the region (Philpott 2020; Pollan 2006). Corn, a high yielding crop adapted to North America, was already the most common crop produced in the region and responded well to N fertilizer and breeding efforts (Pollan 2006). Soybeans largely replaced oats in the mid-twentieth century as a more economical livestock feed and, as a N-fixing legume, more agronomically suited for a simplified rotation with corn (Lockeretz 1988). Oats, once a common horse feed, had also become less useful as mechanized tractors replaced draft horses on the farm (Hart 1986; Lockeretz 1988). Winter wheat, the most common small grain grown in the region after oats, failed to thrive in the region's humid weather (Philpott 2020).

Corn and soybeans became the focus of research, development, and promotion, furthered by policies and investments from the United States Department of Agriculture (USDA) and the US farm bill (Coppess 2018). Public and, later, private breeding programs developed varieties of corn and soybeans to be grown as packages with synthetic pesticides and fertilizers (Cochrane 1993; Fernandez-Cornejo and Just 2007). Commodity and conservation programs started during the Great Depression encouraged the large-scale production of a small set of commodities, including corn and later soybeans (McGranahan et al. 2013; Ramey 2014). After World War II, subsidized global export markets incentivized farmers to increase their production of these core US commodities (McGranahan et al. 2013). As production increased, state-sponsored agricultural experiment stations and private industry developed market outlets and accompanying processing for a range of corn and soybeans products, including livestock feed, ethanol, oil, sweeteners, and additives (Lockeretz 1988; Pollan 2006). The markets and price for corn further surpassed those of other row crops when, in 2005, the US federal government passed the Renewable Fuel Standard. The act mandated that a portion of all motor fuel contain renewable biomass (ethanol), which is most commonly made from corn due to its high carbohydrate content (Mosier and Ileleji 2006; Johnson et al. 2021).

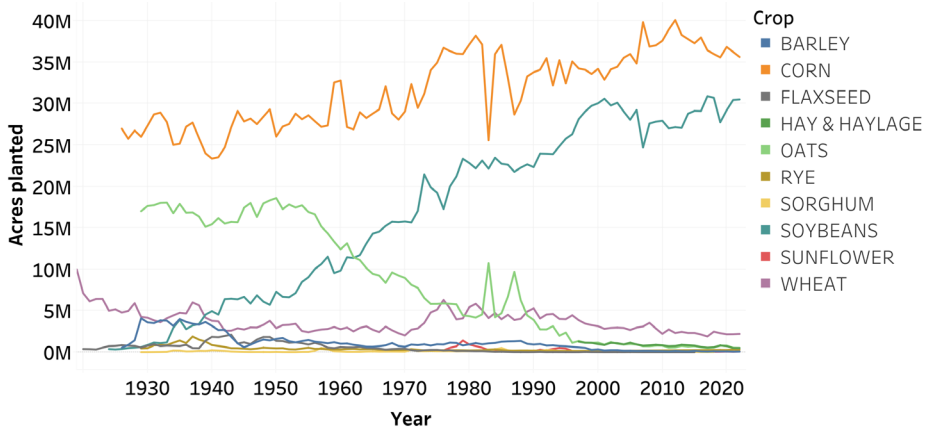
Geographical concentration in agricultural processing and manufacturing occurred alongside changes in agricultural production (Hendrickson and James 2005). Beginning in the mid-1800s with the construction of new transport infrastructure for grain, grain handling and milling industries consolidated significantly, resulting in the centralization of processing facilities (Halloran 2015; Hendrickson and James 2005; Howard 2016), leaving fewer local buyers for small grains. In the example of wheat, as flour production increased, the number of mills declined from 22,573 in 1870 to 170 in 2010 (Kim et al. 2001; Posner and Hoseney 2015).

Together, these structural changes made it easier economically and agronomically to grow corn and soybeans in the Upper Midwest and harder to grow other crops. This led to a decline in cropland devoted to other field crops in the region, most notably small grains (Figure 1). Oats experienced the greatest loss, with planted acreage in the region falling by 97% from 1929 to 2022. During the same period, corn acreage grew over 37% and soybean acreage grew fiftyfold. As of 2022, small grains made up 0.7% of total field crop acres planted in the region (USDA NASS 2022). Production of small grains shifted to more arid areas to the west with a geographically comparative advantage for growing small grains and where corn production is less suitable. In addition to domestic production in the Western and Great Plains states, the United States is also a net importer of oats and rye and imports substantial amounts of wheat and barley, primarily from Canada (FAO 2022; World Bank n.d.). Multiple grain-based food companies, such as Quaker Oats, have processing facilities in the Upper Midwest, but purchase grain from other US regions and from abroad (Eller 2017). Some food companies have begun efforts and conducted pilot projects to source small grains from the Upper Midwest to meet sustainability goals (Barnstable 2021).

Conceptual framework

Unlike the adoption of conservation practices, the production of small grains in the Upper Midwest often requires the displacement of corn

Figure 1. Acres planted of major field crops from 1919 to 2022 in the states of Iowa, Illinois, Wisconsin, and Minnesota. Note: Beans (dry edible), canola, chickpeas, cotton, hemp, peas, sorghum, and sugar beets were minor crops (generally below 500,000 ac planted over this time period) and were removed from this graph for readability.



and soybeans, making their drivers and deterrents likely different. Today, most research on expanding small grain production considers field-level management constraints such as yield (Graybosch and Peterson 2012), N availability (Hitz, Clark, and Van Sanford 2017), pests and disease (Ghimire et al. 2020; Jin et al. 2018), weeds (Tautges et al. 2017), and improved varieties (Sadok et al. 2022; Sandro et al. 2022). In the United States, only a few studies have explored the barriers and drivers of growing small grains past the farm gate. Baker and Russell (2017) and Muckey (2018) conducted qualitative studies focusing on supply chain development. Baker, Meints, and Hayes (2020) surveyed organic barley growers in the United States on the primary obstacles to growing the crop, and Weisberger et al. (2021) surveyed Iowa farmers about their perceived barriers and benefits of small grains in extended rotations. Across studies, markets were found to be a key determinant to the production of small grains and collaboration across stakeholders in the supply chain necessary to improve the market opportunities available to farmers.

Given the importance of external factors such as markets identified in the limited extant literature on barriers to small grain adoption, and responding to scholars noting the sparse exploration of the role of structural factors in the adoption of conservation practices (Prokopy et al. 2019; Stuart and Gillon 2013), in particular policies and programs (Carlisle 2016; Fleckenstein et al. 2020), this research makes a focused effort to include factors that can be changed or supported at the policy-level (i.e., farm bill policies, markets, technical assistance, and publicly funded research priorities). To do so, we add the role of structural factors to existing theories on the importance of drivers of behavior prevalent in adoption literature such as social norms, beliefs, and attitudes (Ajzen 1991; Fishbein and Ajzen 2010; Stern et al. 1999).

Exemplified by the theory of constrained choice (Hendrickson and James 2005), we hypothesized that farmers are particularly limited in their abilities to make decisions about growing a small grain due to larger structural conditions. According to the theory of constrained choice, farmer agency is constrained by low profits from grain farming, requiring farmers to specialize and grow their operations to take advantage of economies of scale and in turn resulting in higher capital costs and larger debt loads (Hendrickson and James 2005). The constant pressure to increase productivity to cover input and land rent costs makes it difficult to consider alternative and potentially riskier production strategies (Buttel 2006; Hendrickson and James 2005). Moreover, concentrated markets relegate farmers to the position of "price takers," where what is grown is dictated by an increasingly fewer number of buyers who determine the price farmers receive (Hendrickson and James 2005). Over time, farmers lose the skills necessary to produce

alternative crops and production systems (Fitzgerald 1993; Hendrickson and James 2005). Applying this concept to small grain production in the Upper Midwest, we predict that farmers are constrained in their abilities to choose to produce a third crop such as a small grain due to key structural factors such as a lack of technology and equipment to support production and a lack of existing markets and infrastructure for the processing and sale of small grains.

To only examine external, structural factors, however, would be to ignore the complexity of the environment in which farmers make decisions. In this study we include a range of operational, biophysical, and individual factors shown to be important to farmer decision-making in addition to political, economic, and social factors (Baumgart-Getz, Prokopy, and Floress 2012; Carlisle 2016; Prokopy et al. 2019). Building on the limited existing social-science research on the drivers of small grain production, this paper represents the first mixed methods study to attempt to holistically understand farmer decision-making around small grains.

MATERIALS AND METHODS

This study used a mixed methods design to triangulate and enrich the ways in which we understand farmer decision-making and the factors that impact it. Mixed methods involve the collection and analysis of both qualitative and quantitative data. Integrating qualitative and quantitative results allows us to use the complementary strengths of each to reach more robust conclusions and deeper insights (Creswell 2018; Johnson, Onwuegbuzie, and Turner 2007). The study also employed a participatory approach by including farmers and community partners in the design and implementation of the research. Participatory research can shed greater light on the research problem by providing a more complete or nuanced understanding of the phenomena and ensure that results are applicable and useful to key stakeholders (Breitbart 2016). This project was collaboratively developed by individuals at several academic and nongovernmental organizations (NGOs) including the University of Wisconsin–Madison; the Michael Fields Agricultural Institute; the Artisan Grain Collaborative; the University of California, Davis; and Purdue University and guided by a Project Advisory Council made up of farmers and key experts and decision-makers in small grain production in the region.

We define small grains as barley (spring and winter), Kernza, oats, rye (cereal and hybrid), triticale (spring and winter), spelt (*Triticum spelta* L.), and wheat (spring and winter). We focused on the states of Iowa, Illinois, Minnesota, and Wisconsin due to their significant potential for small grain production, and their growing artisan baking, distilling, and brewing sectors (AGC 2024b). The University of California, Davis Institutional Review Board reviewed this project under ID number 1822228-1 and determined it to be Exempt.

Farmer survey: Data collection

A farmer survey was disseminated between January and April of 2022 during a time when farmers are most available in the region as they have finished harvesting and have yet to begin spring planting. The survey questions were focused on individual and operational characteristics, the barriers to and drivers of growing small grains, the support programs available to farmers, beliefs about the benefits of small grains in rotations, and the most reliable sources of information regarding small grains. For those who currently grow or have grown small grains in the past, we asked about the kinds of markets and contracts they use for selling their grain, and any infrastructure limitations (see online Supplementary Materials, Appendix 1). The survey was developed in collaboration with the Project Advisory Council and Artisan Grain Collaborative (AGC)'s Farmer Collaboration Working Group (a peer group of farmers supporting food-grade small grain production) and piloted with several other farmers to ensure clarity of questions, and appropriate length.

We disseminated the survey through several routes. First, we sent the survey to 3,125 farmers using a stratified randomized sample of farmer addresses purchased from DTN, a data analytics and technology company. We limited our sample

to those whose farm address was within one of the four study states and who were farm operators, and to ensure we did not sample hobby farmers, we included corn and/or soybean farmers who farmed at least 40 operational acres (~16 ha; as opposed to land leased to others or land in pasture) and farmers growing small grains and not corn or soybeans who farmed at least 10 operational acres (~4 ha). We targeted corn and soybean farmers due to their predominance on the landscape. The lower acre threshold for small grain farmers as opposed to corn and soybean farmers was chosen because small grains can be found on operations of a variety of sizes, including small-scale. To strive for representation from farmers who had and had not grown small grains, we constructed a stratified sample frame based on available farmer profile data from DTN, including crops grown. Within the DTN database, we took a random sample of 50% of farmers who grew corn and/or soybeans and no small grains and 50% of farmers who grew small grains. The resulting sample was comprised of 38.5% of farmers who had grown corn and/or soybeans with at least one small grain and 11.5% of farmers who had not grown corn or soybeans but grew at least one small grain. We disseminated the survey through both postal mail (1,125) and email (2,000) to reach a broader population of farmers with varying access to the internet and comfort with email.

We sent out three waves of contact following Dillman (2014) as a guide for each route of dissemination. For postal mail surveys, we sent the survey and two follow-up postcards. For the online survey, we sent an email with an invitation to take the survey through the digital survey software Qualtrics, one follow-up email, and one follow-up postcard. After excluding undeliverable addresses and those no longer farming from post mail surveys (85), we received usable surveys from 259 farmers with a response rate of 25%, an acceptable rate among farmer surveys, especially given declining response rates of mail surveys (Stedman et al. 2019). For the online surveys, after removing 19 undeliverable email addresses, we received 80 usable surveys with a response rate of 4%. Online survey response rates tend to be substantially lower than post mail (Nulty 2008; Ulrich-Schad et al. 2022) and vary widely (Dunn et al. 2016; Wardropper et al. 2021). When excluding the online surveys from the sample, the results were almost identical. For this reason, despite the low response rate, we include these observations to add to the robustness of our results.

Next, after finding few organic small grain farmers had responded in the first several weeks of the postal mail and email surveys, we decided to purposely sample additional organic farmers in order to have a large enough sample size to draw conclusions about this group. We sent the survey through two additional online routes: to farmer email addresses from the USDA Organic Integrity database and through the Organic Grain Resource and Information Network (OGRAIN) listserv, a network of farmers in the Upper Midwest growing organic grains. We collected email addresses from the USDA Organic Integrity database for those farming at least one small grain and sent an email invitation to take the survey, one follow-up email, and one follow-up postcard. We received usable surveys from 41 farmers for a response rate of 14%. In addition, we sent an email through the OGRAIN listserv inviting farmers to take the survey. We received responses from 27 farmers for a response rate of 4% using the number of farmers subscribed to the list. While the response rates are low for the organic-specific routes of dissemination, we believe that they are acceptable given the limited population size of small grain farmers who are also organic, making them difficult to reach. According to data from USDA, only 0.4% of operations grow organic small grains in the Upper Midwest (USDA NASS 2016, 2017).

Our total sample size combining all dissemination routes is 406 farmers and landowners. We believe this to be a robust sample size given that a conservative sample size calculation showed a need for at least 384 responses from the estimated 146,326 population of farmers raising corn, soybeans, and/or small grains in the study states for appropriate statistical power using a 95% confidence interval and 5% margin of error. We also acknowledge, however, that like most survey samples, selection bias is likely present. Individuals with more time and who were more interested in the subject of the survey may have been more

likely to respond. We stated in bold in the survey cover letter that small grains in extended rotations can increase yields of corn and soybeans to encourage corn and soybean farmers who may not have been interested in small grains to fill out the survey.

Farmer survey: Analysis

In addition to reporting summary statistics, we used correlational network mapping to explore the factors associated with whether a farmer grows small grains. Correlation network mapping uses the concept of social network mapping (Prell 2012) to visualize relationships between variables where the "node" is the variable and the "edge" is the bivariate pairwise correlation (Epskamp et al. 2012). Correlation network mapping allows us to understand whether and to what extent the independent variables are associated with whether a farmer grows small grains, the valence of the relationships between variables (i.e., positive or negative relationship), and the relationships between the independent variables. This method also allows us to analyze all relevant independent variables, including those with small sample sizes (which was the case for several of the policy variables for which farmers were less inclined to answer) that lack statistical power to meaningfully analyze in a regression. We chose independent variables based on an iterative process including those that were actionable by the farmer or decision-maker in agriculture (see *Conceptual framework* section), have been shown to be associated with the use of diversification practices and conservation practices in existing literature (Baker, Meints, and Hayes 2020; Baumgart-Getz, Prokopy, and Floress 2012; Carlisle 2016; Prokopy et al. 2019; Roesch-McNally, Arbuckle, and Tyndall 2018; Weisberger et al. 2021), were highly correlated with whether a farmer grows small grains, and through bidirectional stepwise selection. Table 1 describes the variables used in the correlation network, including the variable name, the original survey question, its quantitative coding, the number of observations, and the sample mean. We used Pearson's correlation in the correlation network to compare coefficients across variables with the same measure of correlation. Pearson's correlation coefficient can be used to measure the relationship between two nonlinear binary variables in addition to linear relationships between continuous variables (Duan et al. 2014). We tested the robustness of Pearson's correlation with Cramér's V, a nonparametric measure of association suitable for nominal variables. We conducted additional checks on binary variables to verify the direction of the statistical relationship through plots and odds ratios. We found similar results across all tests.

Focus groups and interviews: Data collection

To verify our survey findings and gain insight into the causal direction of statistical relationships, we held a series of focus groups and interviews with farmers and nonfarming agri-food professionals from July to September of 2022. These focus groups enabled us to explore issues that may not have emerged through surveys, gain a more in-depth understanding of the survey results, and identify opportunities to overcome barriers and build upon the drivers of adoption identified in surveys. Focus groups are a method of data collection that facilitate the development of innovative solutions through the sharing of personal experiences and insights among participants (Bosco and Herman 2010; Cameron 2005). For this reason, we used focus groups when possible; however, we held interviews with individual farmers who were not able to join a focus group and with nonfarming agri-food professionals with few peers with whom to form a group. We timed the interviews and focus groups to occur during off periods from planting and spraying across corn, soybean, and small grain production.

Using Martí's (2016) framework for sequentially integrated research designs in participatory research, farmer surveys informed the selection of participants and the identification of research questions for the focus groups and interviews. Fifteen farmers were recruited based on an indicated interest in participating in the farmer survey. The remaining farmers were recruited through partner organizations to ensure representation from current, discontinued, and non-small grain farmers across all four study states. Nonfarming agri-food professionals were purposefully selected to provide expert opinions based on the factors

Table 1. Variables included in the correlation network.

Variable name	Question [notes]	Coding	*N*	Mean
Grows small grains	Which of the following best describes your operation regarding small grains: I have grown small grains as a cash crop or cover crop at some point in the last 6 years; I have not grown small grains in the last 6 years, but have grown them in the past; I have never grown small grains	1 = if yes in the last 6 years; otherwise, 0	406	0.67
Farmer age	What year were you born? [Age calculated from 2022]	Continuous	375	61
Total acres	Please estimate the acreage of your farmland in 2021: Total acreage (owned + rented/leased)	Continuous	393	671
Percent acres owned	Please estimate the acreage of your farmland in 2021: Acres owned (operated or rented to others) [Percentage calculated from this and above question]	Ranges from 0 to 1	338	0.65
Livestock on-farm	Did your operation raise livestock, either for sale or for on-farm use in 2021?	1 = yes; 0 = no	395	0.47
Certified organic	*All or some of* my operation was certified organic	1 = yes; 0 = no	405	0.20
No-till/conservation tillage	*All or some of* my operation was farmed using no-till or conservation tillage practices	1 = yes; 0 = no	405	0.50
*Cost share available**	Are/were small grains cost shares or conservation incentive payments (e.g., EQIP or CSP) to grow small grains available to you?	1 = yes; 0 = no	158	0.65
*Crop insurance available**	Are/were small grains cost shares or conservation incentive payments (e.g., EQIP or CSP) to grow small grains available to you?	1 = yes; 0 = For only some of my small grains; 0 = No	196	0.79
Information source: other farmers	Please select the top 3 most reliable information sources regarding small grains: other farmers	1 = yes; 0 = no	371	0.75
Information source: fertilizer, chemical, or seed dealers	Please select the top 3 most reliable information sources regarding small grains: fertilizer, chemical, or seed dealers	1 = yes; 0 = no	371	0.46
Information source: university extension	Please select the top 3 most reliable information sources regarding small grains: university extension	1 = yes; 0 = no	371	0.41
Belief: improves health of soils	Select any of the following statements that you believe are true regarding small grains in rotations: They improve the health of soils	1 = yes; 0 = no	389	0.65
Belief: mitigates risk	Select any of the following statements that you believe are true regarding small grains in rotations: They mitigate risks	1 = yes; 0 = no	389	0.33
Belief: increases yield	Select any of the following statements that you believe are true regarding small grains in rotations: They increase the yields of corn and soybean crops	1 = yes; 0 = no	389	0.44
Belief: reduces chemical needs	Select any of the following statements that you believe are true regarding small grains in rotations: They reduce chemical requirements for pest and disease management	1 = yes; 0 = no	389	0.53

Notes: EQIP = Environmental Quality Incentives Program; CSP = Conservation Stewardship Program.
*For both *cost share available* and *crop insurance available,* those who chose "I don't know" were not included. Doing so removes the possibility that the variables become more strongly correlated with *grows small grains* due to the likelihood that those who grow small grains are more knowledgeable regarding whether cost share or crop insurance for small grains is available to them simply because they already grow them.

farmers identified as important to their decision-making around small grains in the survey.

We created semistructured interview and focus group protocols tailored to each type of key informant (see online Supplementary Materials, Appendices 2 through 5) and conducted separate focus groups and interviews with each type of participant: current small grain farmers, discontinued small grain farmers, non-small grain farmers, and nonfarming agri-food professionals. For current small grain farmers, we focused on farmers' experiences growing small grains; for discontinued small grain farmers, we focused on why they stopped growing small grains; and for non-small grain farmers, we focused on their thoughts on small grain production. The farmer protocol began with a general question on barriers and drivers of small grain production, and we then asked specific questions about the common barriers and drivers identified through the farmer survey including markets, infrastructure, government programs, and research and information needs. Questions for nonfarming agri-food professionals varied based on the sector of the participant, but they generally gauged the barriers and opportunities for small grain production in the region and built upon findings from the survey. Thematic memos were completed mid-way and at the end of the period in which we conducted the interview and focus groups to summarize and reflect upon findings as data collection occurred (Corbin and Strauss 1990).

A total of 39 individuals participated in 15 in-depth, semistructured interviews and five focus

groups, including 22 farmers and 17 nonfarming agri-food professionals. Of the participating farmers, 14 currently grew small grains, 5 had discontinued, and 3 had never grown small grains. Nonfarming agri-food professionals included a crop insurance salesperson, an agricultural lender, a small grain buyer, two small grain brokers, a small grain miller, two Cooperative Extension professionals who work with corn and soybean farmers, five academics researching small grain production, and three advocates working for national and regional NGOs that support small grain production. Interviews and focus groups were conducted either in-person, via Zoom, or by telephone and lasted between 25 to 102 minutes.

Focus groups and interviews: Analysis

Audio recordings of focus groups and interviews were transcribed using TranscribeMe! transcription service (TranscribeMe!, San Francisco, California). A total of 1,145 minutes were transcribed. Quality checks on the data were performed when transcripts were unclear and were edited as needed. Data were analyzed in NVivo software (version 1.6.2). Using a combined deductive and inductive coding process, an initial codebook was developed with key themes that arose from surveys and the limited literature on the adoption of diversified farming systems (deductive), and key themes identified after reading transcripts (inductive). Further "emergent" themes were added during the process of coding. Nonfarming agri-food professional transcripts were analyzed to provide explanation or further detail to key themes emerging from farmer transcripts and to inform recommendations. Key themes were verified by conducting keyword searches of the transcripts. While a key theme did not need to be identified by all farmers in the sample (Deterding and Waters 2021), we were careful to note negative cases (instances where a farmer had an opposing viewpoint to the majority) (Corbin and Strauss 1990).

RESULTS AND DISCUSSION

Results by method

Of the farmers we surveyed, 23% resided in Iowa, 29% in Illinois, 24% in Minnesota, and 24% in Wisconsin. The majority, or 67% ($n = 271$), grew small grains as a cash crop or cover crop at some point in the last six years (categorized as "current small grain farmers" for the purposes of this study), 17% ($n = 71$) grew them in the past but not in the last six years (categorized as "discontinued small grain farmers"), and 16% ($n = 64$) had never grown small grains (categorized as "non-small grain farmers"). We note that while we strived for an even distribution between those who have and have not grown small grains through our stratified sampling procedure, our sample resulted in an overrepresentation of current and discontinued small grain farmers. This is likely because the topic was more salient to small grain farmers who were then more motivated to take the survey. However, the number of observations of non-small grain farmers was sufficient to perform statistical analyses. The average age of farmers in the survey was 61 years old, the average farm size was 671 ac (271.5 ha), and the median farm size was 340 ac (137.6 ha). The geographic distribution, age, and average farm size of the sample are representative of the larger corn, soybean, and small grain farming population in these states according to the 2017 USDA Census of Agriculture (see online Supplementary Materials, Table S1). The average farmer owned 65% of their land, and 47% of farmers raised livestock in addition to crops. In terms of farming practices, 20% of farmers were organic or transitioning to organic, and 50% used no-till or some form of conservation tillage (Table 1).

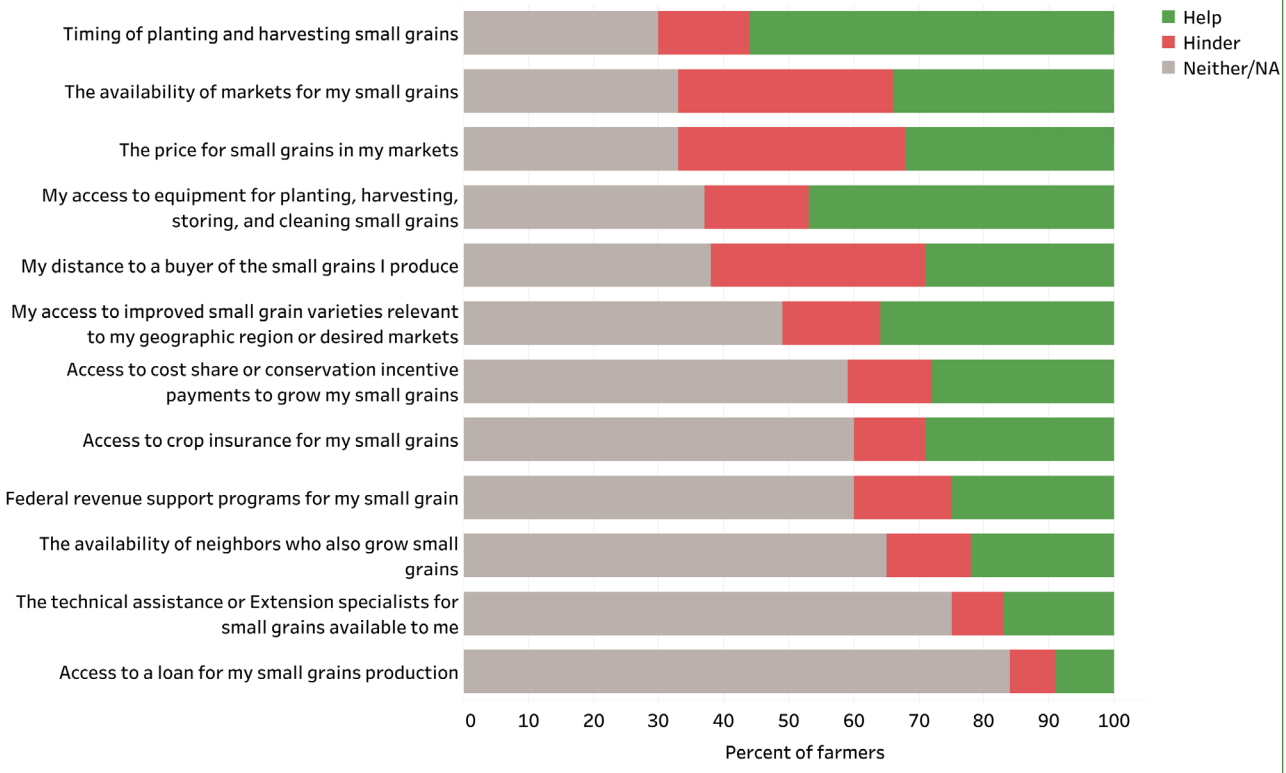
To understand what determines whether a farmer grows small grains, we used three main ways of knowing: (1) what farmers themselves reported as the barriers and drivers through a quantitative survey, (2) the associations found through statistical analysis between individual and farm-level variables and whether a farmer grows small grains, and (3) what farmers discussed as barriers and drivers during qualitative focus groups and interviews. Each method allows us to analyze different but complementary factors in multiple formats to provide a more comprehensive analysis of the determinants of small grains adoption. We describe the main results of each below.

Farmer-reported results

According to small grain farmers, economic factors—the price for small grains in their markets, the availability of markets, and the distance to a buyer of the small grains they produce—pose the largest hinderance to their ability or willingness to plant small grains, whether for sale or for on-farm use (Figure 2). Results were similar across farmers who grew small grains for sale and those who grew them for on-farm use only. Economic factors, however, can be both a helping and hindering force, and each were about as commonly selected as factors that *helped* farmers plant small grains (markets 34%; prices 32%; distance to a buyer 29%) as factors that *hindered* them (markets 33%; prices 35%; distance to a buyer 33%). The factors that small grain farmers selected the most as helping were the timing of planting and harvesting small grains (56%); access to equipment for planting, harvesting, storing, and cleaning small grains (47%); and access to improved small grain varieties relevant to their geographic area or desired markets (36%). The availability of neighbors who also grow small grains; the availability of technical assistance or Cooperative Extension specialists for small grains; and access to a loan for small grain production were not commonly listed as either helping or hindering small grain farmers.

The policy factors, or those determined by the US farm bill, were most commonly selected as neither helping nor hindering or not applicable, although each was more commonly listed as helping farmers (crop insurance 29%; cost share 28%; revenue support 25%) compared to hindering them (crop insurance 11%; cost share 13%; revenue support 15%). Access to crop insurance for small grains, access to cost share or conservation incentive payments for small grains such as the Environmental Quality Incentives Program (EQIP) or Conservation Stewardship Program (CSP), and federal revenue support programs for small grains including Price Loss Coverage (PLC), Agriculture Risk Coverage (ARC), and the Marketing Assistance Loan program (MAL) were listed as the seventh, eighth, and ninth most important

Figure 2. Self-reported factors that help or hinder the ability/willingness of current small grain farmers to plant small grains, whether for on-farm use or for sale.



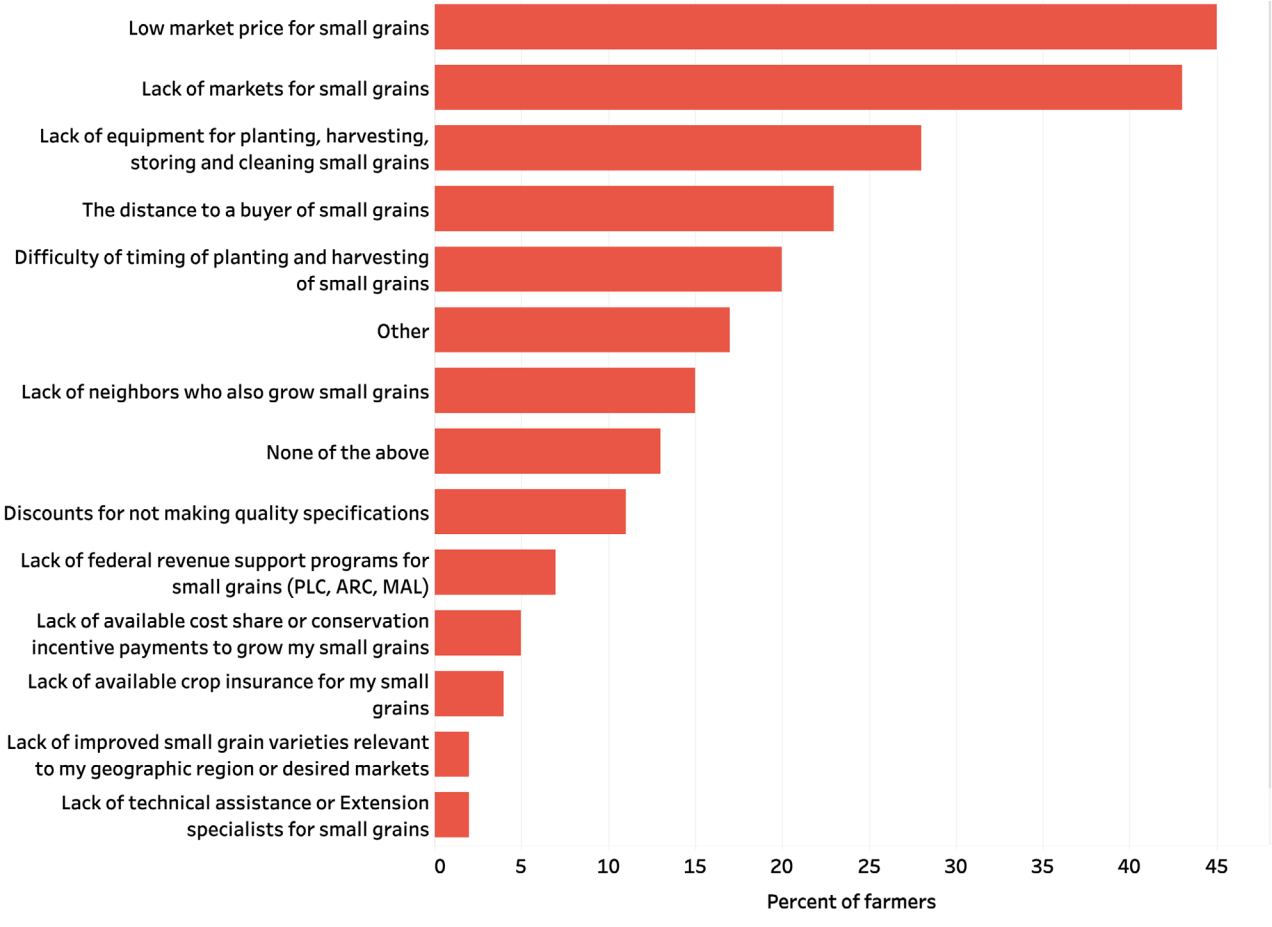
factors (out of 12), respectively, that helped farmers to grow small grains.

Farmers who discontinued their small grain production and those who had never grown small grains reported that low market prices (45%) and a lack of markets (43%) for small grains were the most important barriers to production (Figure 3). Lack of equipment for planting, harvesting, storing, and cleaning (28%); distance to a buyer (23%); and difficulty of timing and planting small grains (20%) were also frequently listed as barriers. "Other" (17%), including lack of livestock, age, labor, difficulty of production, yield, and profitability; lack of neighbors growing small grains (15%); and discounts for not making quality specifications (11%) were in the middle of the ranking of the most important barriers selected. Like current small grain farmers, discontinued and non-small grain farmers did not commonly select lack of federal revenue support programs (7%), cost share (5%), crop insurance (4%), technical assistance (2%), nor access to loans (1%) as barriers to production. Fewer discontinued and non-small grain farmers selected access to improved varieties as a barrier (2%) compared to current small grain farmers (36%).

Correlation network results

Farmer-reported results show that external economic factors such as availability of markets and market prices are important barriers to and drivers of adoption. While markets and prices may vary depending on geographic location, many farmers with equal access to markets and similar available prices make different decisions regarding small

Figure 3. Self-reported barriers to small grain production among discontinued and non-small grain farmers.



grain use. To begin to understand what distinguishes these farmers, we used a correlation network to show the strength of the connections between growing small grains and the individual and farm-level factors that vary across farmers, as well as how these factors are related to each other.

Figure 4a displays all correlations present across all variables, evidencing the complex interconnection between the factors that can influence farmer decision-making around cropping choices. Figure 4b shows only the strongest correlations with a minimum threshold of $r = 0.25$. A threshold of 0.25 was chosen after finding two clear groups ranging from –0.08 to 0.20 and from 0.25 to 0.37, with the latter of the two showing the strongest correlations. We found that the factors most strongly associated with growing small grains are the following: reporting that cost share or conservation incentive payments (e.g., EQIP, CSP) for planting small grains were available ($r = 0.37$), believing that small grains in rotations improve the health of soils ($r = 0.30$), operations that were certified organic ($r = 0.28$), believing that small grains in rotations help mitigate risk

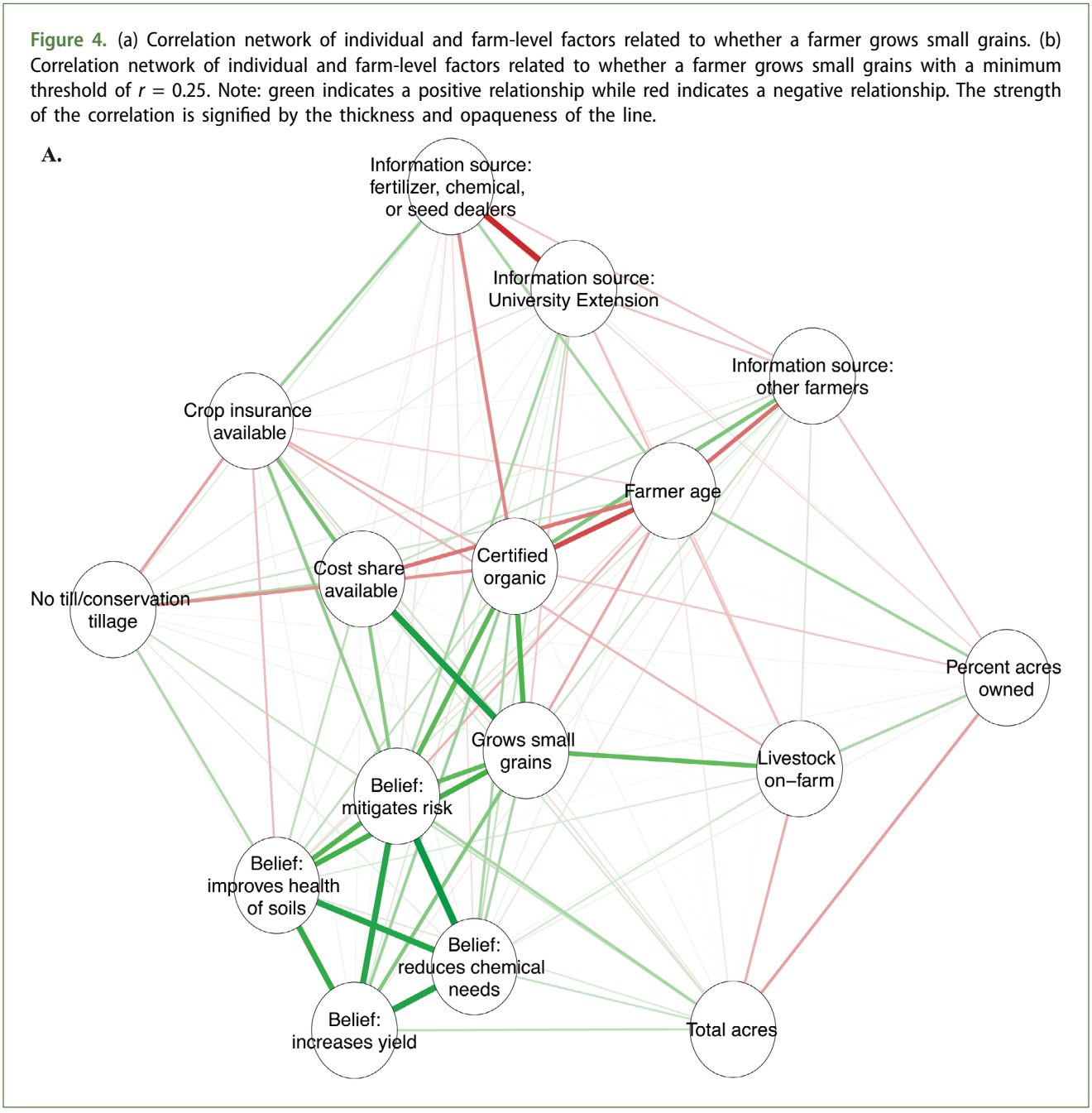
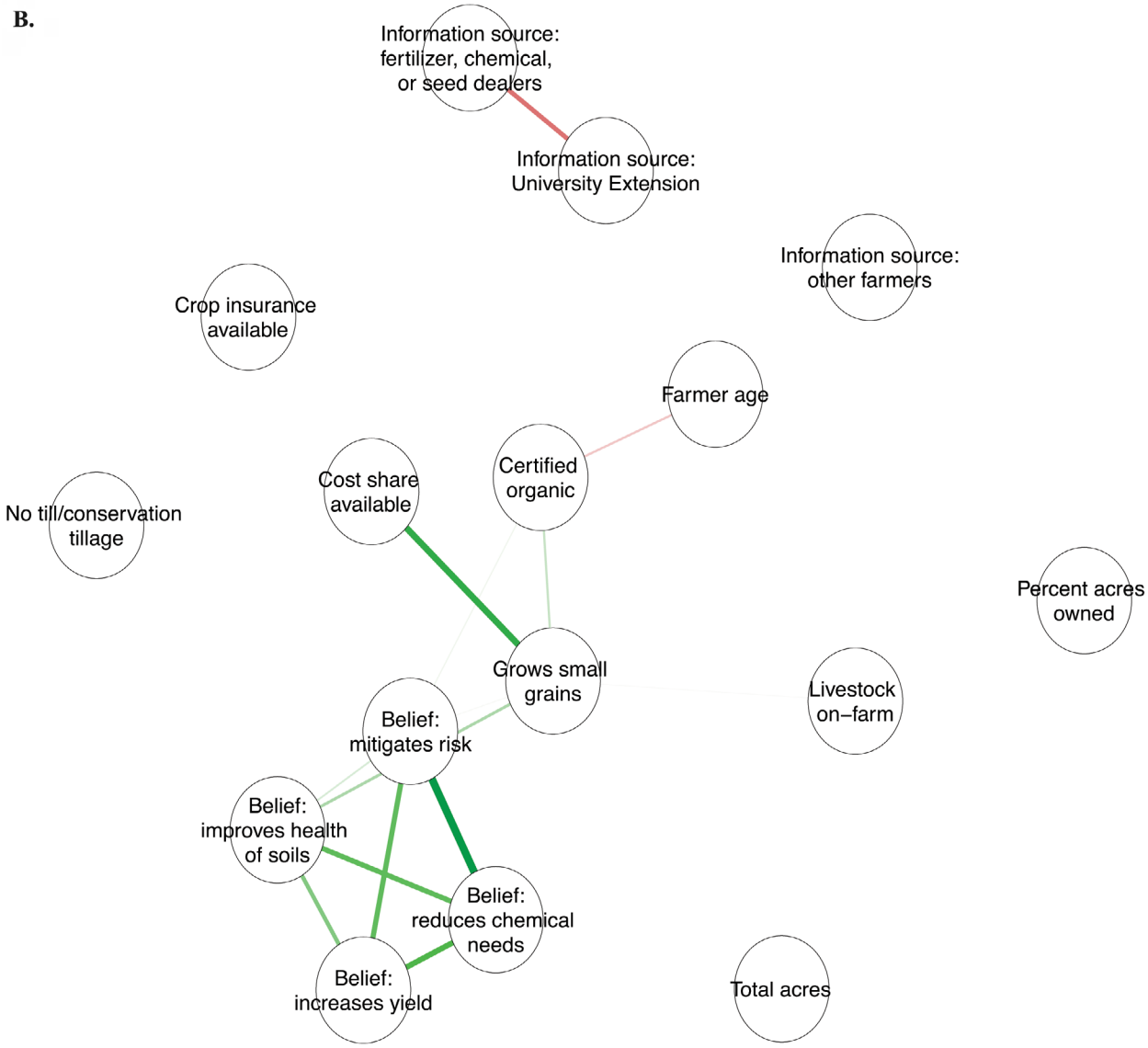


Figure 4. (a) Correlation network of individual and farm-level factors related to whether a farmer grows small grains. (b) Correlation network of individual and farm-level factors related to whether a farmer grows small grains with a minimum threshold of $r = 0.25$. Note: green indicates a positive relationship while red indicates a negative relationship. The strength of the correlation is signified by the thickness and opaqueness of the line.

Figure 4. Continued.



($r = 0.25$), and operations with livestock for on-farm use or sale ($r = 0.25$). A logistic regression analysis using a smaller number of observations (89) with data for each variable found similarly significant results for all variables except beliefs in the benefits of small grains to improve soils and mitigate risks. Controlling for all variables in the regression model, significant positive relationships were found between the adoption of small grains and the availability of cost share or conservation incentive payments for planting small grains ($p < 0.00$), organic certification ($p < 0.05$), and livestock on-farm ($p < 0.05$) (see Table S2).

While farmers' beliefs that small grains in rotations improve the health of soils and help mitigate risks are the variables related to farmer beliefs with the strongest correlation with growing small grains, there are strong correlations *between* all four of the belief variables including beliefs that small grains reduce chemical needs and increase yields. Besides connections between beliefs variables, there were no strong correlations between the factors strongly correlated with small grain use. Factors that were not strongly associated with growing small grains include the total acres of the farm, the percentage of those acres that were owned, use of no-till or conservation tillage, farmer age,

availability of crop insurance, and the information source where the farmer turns for small grain needs.

Farmer focus groups and interview results

Farmers shared their insights on the benefits to and challenges of growing small grains in the Upper Midwest and changes and collaborations needed to support their use through focus groups and interviews. Of the 22 farmer participants, 15 currently grew small grains, 4 had discontinued, and 3 had never grown small grains and grew only corn and soybeans. Participating small grain farmers grew a range of crops, including corn, soybeans, small grains, alfalfa (*Medicago sativa* L.), and peas (*Pisum sativum* L.). Four farmers were from Iowa, five from Illinois, six from Minnesota, and seven from Wisconsin. Eight of the farmers were certified organic, and ten raised livestock in addition to crops.

In Table 2 we identify the most common themes that arose from our conversations during interviews and focus groups with farmers, along with an illustrative example quotation. Overall, farmers' perspectives shared in the interview and focus groups concentrated on many of the same elements identified in the survey results and statistical analysis. Farmers reiterated that price and markets, above all other factors, were the largest barriers to the production of small grains in the region. They also echoed the complexity of the timing of planting and harvesting small grains and the need for equipment for small grain production and improved small grain varieties. The presence of livestock, which was correlated with small grain use in our statistical analysis, also emerged as important for catalyzing small grain production during our conversations with farmers. Factors that were not listed on the survey, but were central during farmer discussions, were the system benefits of small grains, the synergies between cover crops and small grains, the difficult regional growing conditions, and the additional management needs of small grain production as a third crop. As in the survey, farmers noted that support programs such as cost share, crop insurance, and revenue support did not drive their cropping decisions. Focus group

Table 2. The most important factors driving decision-making around small grain production according to farmer focus groups and interviews.

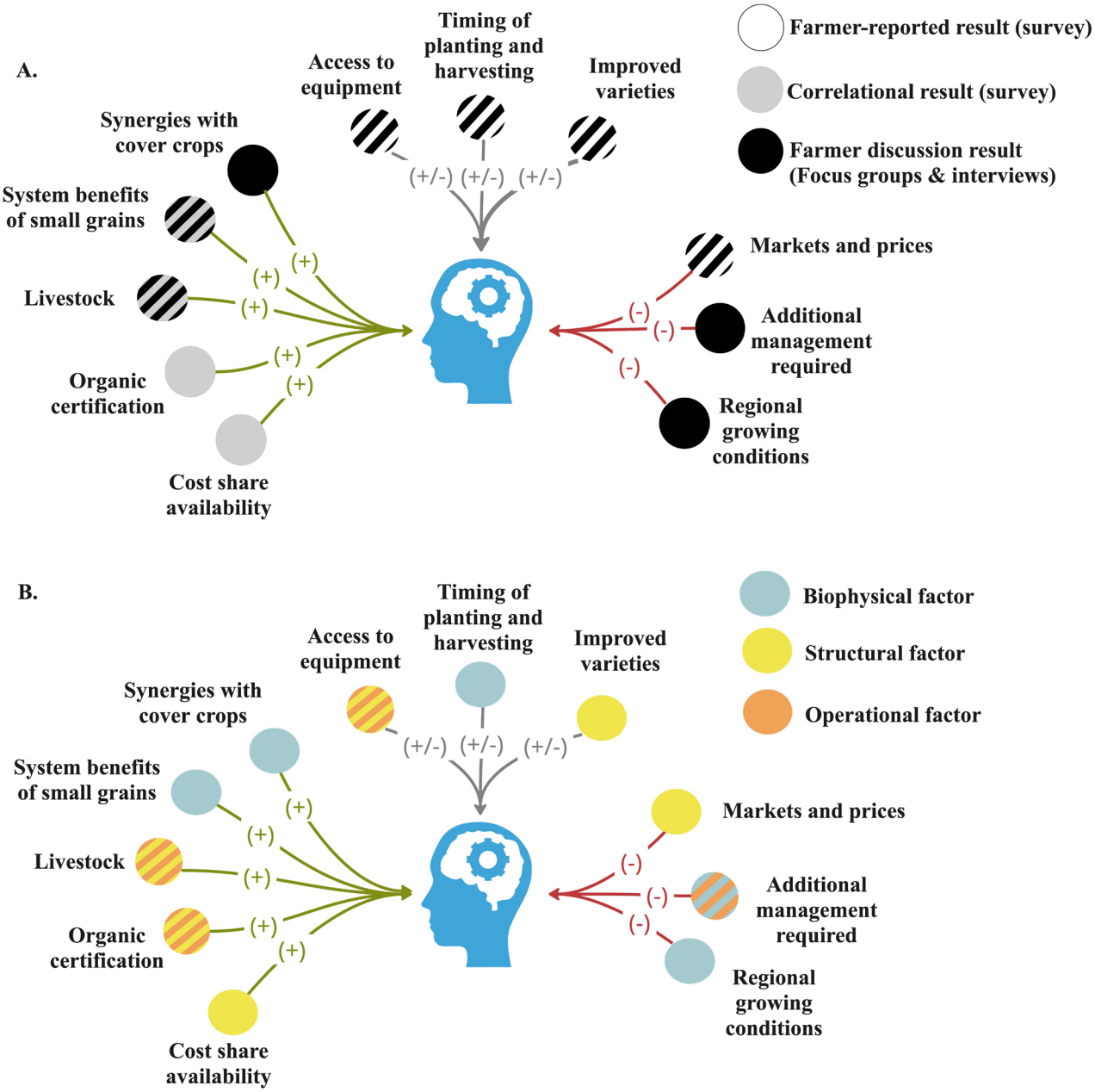
Prominent theme	Example
Price	"Unfortunately, I wish we could raise more and make money off it. But, yeah, there's other ways to make a better living farming than to raise wheat in this country."
Markets	"I guess it gets back to the markets, how difficult is it to market your cash crop. Corn and beans, of course, you just run them to wherever, ADM or local elevator or wherever, and you get the market price. But with oats, it just wasn't that easy."
Timing	"[What] we run into up here just being wet springs. This year, it was a late year. You usually want to start planting around just say 20th of April. We didn't start anything until the 8th of May. So now all of a sudden, it's a tier like that. You didn't get anything seeded and your corn's not in the ground…. It's like, do you want people spending time planting wheat, when all their corn should be getting in the ground. So it's just a complexity of timing issue."
Equipment	"We would have to buy some sort of machine to plant small grains because we don't have a grain drill anymore. At least not a grain drill that's usable. So we would need to invest in that equipment."
Regional growing conditions	"As a grower, you guarantee me the right week of [harvest] weather, and I'll have a whole lot of oats out here. But that just doesn't happen very often."
Improved small grain varieties	"Private investment in breeding stock would be my number one because wheat yields haven't changed comparative to every other commodity out there. I mean take your corn and beans, even sugar beets over the last 20 years. I mean, as a kid, we raised 50-, 55-bushel wheat. Today we're raising 60-bushel wheat. And you compare that in beans and corn or even sugar beets where we're at, and it's ridiculous the amount of advancement we've made; there's a stalemate in the wheat product."
Livestock	"The small grain paradigm evaporated when the livestock left farms. Every dairy farm used to grow its oats or barley and go in a rotation like that, and now it's the big farms or the dairies and nobody else does it."
System benefits	"It's probably the one thing that keeps me from completely dumping spring wheat or barley or whatever on the farm there is, just there are some benefits to having that, in our case, fourth crop in the rotation. And you can't put a dollar figure on it right now, but there's an advantage to it. So we keep a little bit around for that reason."
Synergies between small grains and cover crops	"I don't have all the solutions, obviously, but I see that farmers know they need small grains. Even our conventional neighbors are planting cover crops. It won't be long to convince them, right? They're already planting rye as a cover. It's kind of getting there."
Additional management	"I mean, there's a few guys who are, 'Yeah, I want the easy.' Easy is corn and soybeans … everything's all set up for it."

and interview results are further illuminated in the next section.

Integrated results and discussion by determinant

We now discuss in further detail the key determining factors of whether a farmer grows small grains across multiple methods and ways of knowing (farmer-reported survey results, correlational network mapping, and focus group and interview results) and multiple types of factors (biophysical, structural, and operational) (Figure 5). We include additional summary statistics from surveys and results from in-depth interviews and focus groups with nonfarming agri-food professionals to

Figure 5. (a) Determinants of small grain production by method and way of knowing. (b) Determinants of small grain production by type of determinant. Note: shading of circles indicates the method used to determine the result (for a) or type of determinant (for b). Striped shading shows multiple methods (for a) or types of determinants (for b) supporting the same result.



understand how and why these factors impact small grain production.

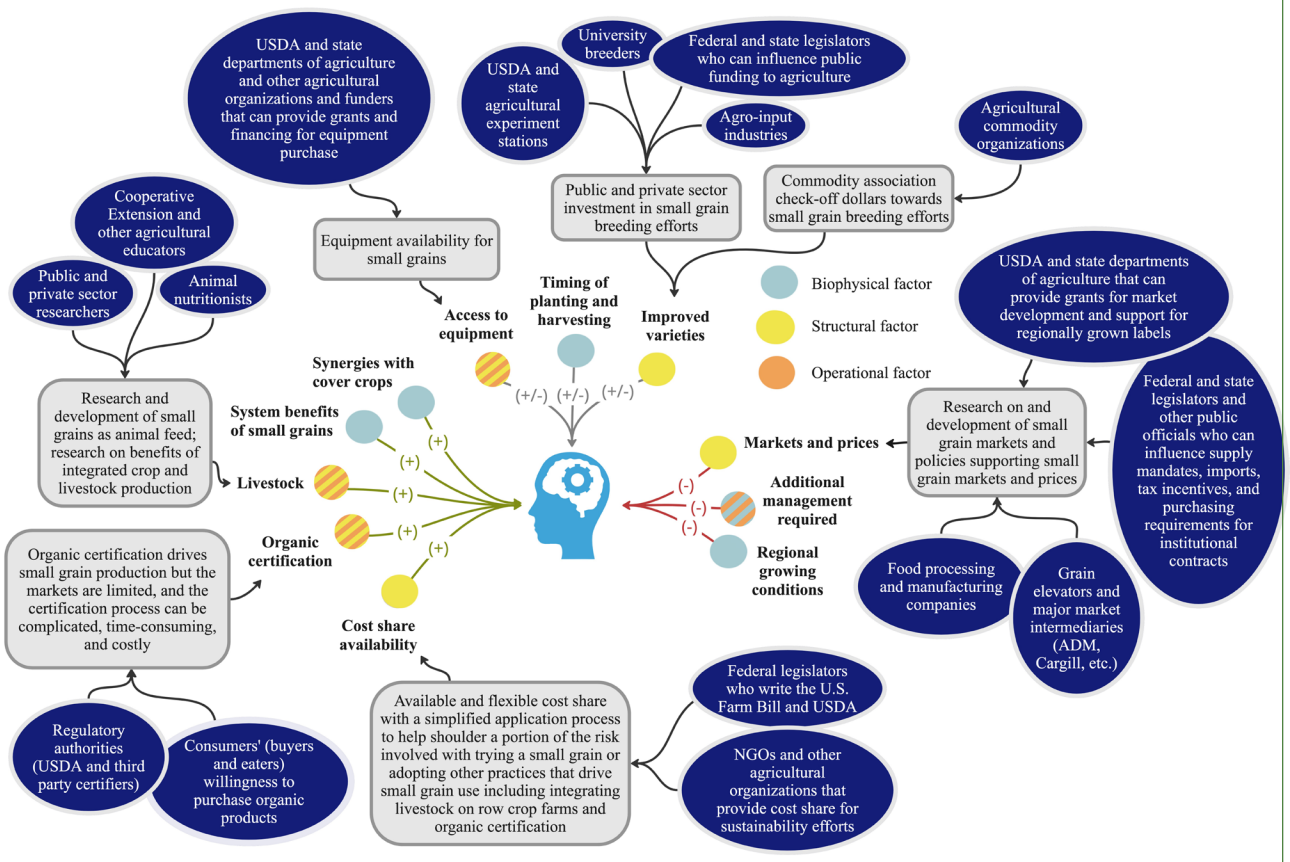
Across all methods we found that a mix of biophysical, structural (social, economic, and political), and operational factors act as both barriers and drivers of farmers' decision-making around small grains (Figure 5a). Markets and prices, regional growing conditions, and additional management were the strongest barriers to small grain production. Access to equipment, improved small grain varieties, and timing of planting and harvesting could be both drivers and barriers to production depending on the farmer. Livestock, cost share programs, the system benefits of small grains, the synergies between small grains and cover crops, and organic certification were found to be drivers of production.

Crop insurance and revenue supports (ARC, PLC, and MAL) for small grains, access to a loan for small grain production, technical assistance, and availability of neighbors who also grow small grains were not found to be important to a farmer's decision to grow small grains. This is consistent with other literature that shows crop insurance is not a major factor in the adoption of conservation practices (Connor, Rejesus, and Yasar 2022; Fleckenstein et al. 2020) and the limited relative importance of technical assistance (Weisberger et al. 2021). However, other studies have shown that support from peers can help farmers to transition to practices that defy conventional farming norms (Asprooth et al. 2023; Bell 2004). Still, it is difficult to "know what we do not know" in the case of the importance of technical assistance and to acknowledge or understand the influence of farm subsidies and societal pressures.

When broken down by method (Figure 5b), focus groups and interviews generally reinforced survey findings in terms of the importance of markets and prices, access to equipment, timing of planting and harvesting, and improved varieties. Discussions in focus groups and interviews brought out additional factors not included in survey questions such as added management, difficult regional growing conditions, and beneficial synergies with cover crops. Through a combination of focus groups and correlation network mapping, we found that livestock and the system benefits of small grains were also key driving factors. Correlation network mapping identified that organic certification and cost share availability were important factors that did not arise through other methods but were strongly associated with small grain use in our statistical analysis.

As hypothesized, structural factors were particularly apparent and comprised more than half of the identified barriers, reinforcing the idea of Hendrickson and James (2005) that farmers face considerable constraints to growing a crop other than corn or soybeans, given larger forces at work, which they themselves have little ability to change. Farmers interested in planting small grains are limited by the lack of research and development to support small grain production, policies that have historically and continue to provide disproportionate support to corn and soybean production, and limited markets in the region. This is not to say, however, that farmers have no agency to impact or work through these identified structural factors. While it is beyond most farmers' capabilities to create genetically improved varieties, individually, farmers can seek out buyers on their own or with the help of a grain broker or collectively create more localized markets. Still, the most stabilized and easiest way to market grain in the United States is through elevators, where the farmer is a price taker and the crops the elevator purchases are determined by major buyers including Cargill, ADM, and General Mills. Additionally, a farmer could decide, as some in our study have, to grow small grains in rotations purely for their system benefits. However, in an agricultural system that is structured around the industrial-scale production of two crops with well-developed markets and often accompanied by large-debt loads, making a choice that not only requires more management but also typically yields less return in the short term is a difficult one to make. Figure 6 details the structural scaffolding underlying many of the factors behind farmer decision-making and the actors who have the ability to influence those factors. A diversity of actors throughout private industry, academia, NGOs, and government play a role in constraining or enabling the abilities of farmers to grow small grains.

Figure 6. Structural scaffolding underlying determinants of small grain production and key influencing actors.



Markets and prices

The most frequently reported barriers to growing small grains by farmers in surveys, interviews, and focus groups across current, discontinued, and non-small grain farmers were structural factors, including markets and prices. Specifically, farmers reported that the market price, the availability of markets, and the distance to a buyer were the key barriers to integrating small grains into their operations. Weisberger et al. (2021) and Baker et al. (2020) also found that markets and prices were the biggest barriers to production among surveyed farmers. During focus groups and interviews, there was a resounding sentiment that to grow more small grains, more accessible markets were needed with higher prices. A current small grain farmer from Iowa told us: "In North Central Iowa, it's corn, soybean country. If we don't have a solid, dependable market, [small grain production] ain't going to happen. The US$5 discount on the crop insurance—and they can do a little bit on ARC or PLC or whatever. But it's still not going to work if we don't have a solid market." Farmers explained that while small grains require fewer inputs, making them less expensive to grow, and have the potential to market the straw, the return on investment of corn and soybeans is higher.

Given the historic decline of small grain production, farmers explained that their local elevators no longer buy small grains. A discontinued small grain farmer from Minnesota recounted that he had to haul his wheat more than 100 miles (~160 km) to find a buyer "because otherwise the local elevators won't even take it because it's a pain. Because they're all set up for corn and soybeans and where are you going to put a truckload of wheat?" Many farmers said that the distances required to haul their small grains was too far to make production economical. A current small grain farmer from Illinois explained: "You know, I think if we're going to grow wheat, or we're going to grow barley, whatever we can grow, I think you're going to have

to look at a transportation problem.… I have to go somewhere at a distance to us. So that's a problem." As a result of market access issues, several farmers we spoke with have had to sell their grains on conventional (if they were organic) or livestock feed markets at a lesser price after failing to find local buyers for their product.

Because small grain buyers are fewer, successful farm-gate sale requires looking beyond the local elevator and, subsequently, requires more time and effort. Despite these challenges, farmers saw a growing demand for small grains and the potential for future small grain markets. Indeed, when asked about customer preference for local grains, one miller we spoke with shared: "There's definitely bakers in our region who want to be able to communicate [that the grain/flour is local] to their customer base. So, their customer base must be asking. And our bakers then want to be able to communicate the message that it is local."

Farmers and nonfarming agri-food professionals suggested that building consumer markets by launching and building brands for products and byproducts made with diversified crops, promoting regionally grown certifications and labels, supporting more regional processing infrastructure, and developing farmer marketing co-ops are key to supporting small grain markets in the region. Policy levers such as institutional procurement of local grain and tax incentives to both large- (i.e., Oatly and Grain Millers) and small-scale (i.e., Janie's Mill and Meadowlark Farm and Mill) food companies and processors to source grain grown in the Upper Midwest can stimulate production and encourage latent markets. Additionally, removing the corn ethanol mandate within the Renewable Fuel Standard will likely lower the price of corn (Condon et al. 2015) and at the same time make markets for other crops, such as small grains, more competitive.

Timing

Winter and spring cereals occupy a temporal niche in northern cropping systems, creating both opportunities and challenges for farmers. Timing of planting and harvesting was the most frequently selected factor that small grain farmers said helped them in their small grain operations (56% of the sample), while 20% of non- and discontinued small grain farmers listed it as a barrier to production. During focus groups and interviews, farmers emphasized the importance of a new crop fitting well into their existing systems and explained several ways in which the timing of small grains can be both beneficial and detrimental.

Small grain farmers appreciated the window of time after small grains are harvested that allows for a longer growing season for cover crops. Livestock farmers noted benefits from the longer window of time to spread manure afforded by the earlier harvest of spring-planted small grains compared to corn and soybeans. On the other hand, small grain and non-small grain farmers alike were concerned about small grains impacting their ability to tend to their main cash crops—corn and soybeans—especially given the widespread lack of farm labor.

Farmers also acknowledged that planting small grains in the spring and fall is not always easy given the variable weather conditions in the Upper Midwest. Wet springs, a late corn harvest, or an early frost can mean a small grain crop does not make it in the ground in time. According to a current small grain farmer in Illinois, getting a small grain planted in the fall was "great in theory, but we've had some years where we don't get done until it's snowing. So, in a perfect world then, we're done by Halloween or [the] first week in November. It'd be fine. But when we get those years where we're not done [with corn harvest] until Thanksgiving or later, then, all of a sudden, it's like, this isn't going to work. So that's probably another really big concern … is just getting the timing of some of that stuff done."

Equipment

Small grains often require a different set of equipment to plant, harvest, store, and clean compared to corn and soybeans. Equipment for small grains was the fourth most selected factor that *helped* small grain farmers' ability or willingness to grow them. At the same time, lack of equipment was selected as the third most *limiting*

factor for non- and discontinued small grain farmers, just below markets and prices. This tells us that equipment, if accessible, can be a driving force for the adoption of small grains in the region.

Equipment is both a structural factor in that equipment for small grain production is often outdated and difficult to obtain, and an operational factor in that many farmers no longer have equipment for small grains and/or the financial resources to purchase it. One discontinued small grain farmer from Minnesota explained the issue in the context of existing production systems: "They made the corn—feeding the corn to [livestock] so easy. I mean, why would you do something else? Now all of a sudden you need another bin, you need a different planter, you need a different seed." A Wisconsin farmer acknowledged that if it wasn't for his nearby neighbor that helps clear their wheat, he didn't they didn't know where they would take it to be cleaned; "I haven't crossed that bridge, and in that respect then, it would be limited."

Several farmers also suggested that they would grow more small grains if they had more on-farm storage, which allows them to hold onto their product until they find a competitive price. A small grain farmer from Wisconsin explained: "We can't commit to any higher paying or more diversified contracts because we don't really have good storage.… If we had more storage on-farm, that would definitely change the game a bit." More support for, and awareness of, programs that support purchases of equipment and on- and off-farm storage such as the Minnesota Department of Agriculture's Soil Health Financial Assistance Grants to purchase or retrofit soil health equipment and the USDA Farm Service Agency (FSA) Farm Storage Facilities Loan Program are needed to help farmers grow and sell a quality small grain product.

Regional growing conditions

Upper Midwestern climate conditions make small grain production in the region difficult to compete with production in the Central Plains, Western United States, and Canada. Higher levels of rainfall and humidity impact the ability of farmers to meet quality requirements specified for milling and malting. During focus groups and interviews, farmers discussed the trouble of competing with more arid regions to the West that have fewer issues meeting standards of moisture content at harvest (important for proper storage), mycotoxin limits (secondary metabolites produced by molds that are toxic to humans and animals at certain thresholds), falling numbers (amount of preharvest sprouting), and test weights (heft of the grain). Because of these issues, farmers were often paid less than they expected for their small grains due to quality discounts, or had loads rejected, making their production a less reliable source of income compared to corn and soybeans. This was a risk that was often not worthwhile given small grains' lower market prices and distant markets. When asked about what was needed to meet test weights on oats, a common problem for oat farmers, a discontinued small grain farmer from Iowa explained: "Well, that gets into the agronomy department of developing oats, which I think they've worked on quite a bit since I was [growing] it, I hope. But it's still hard to overcome the climate, the weather, and things. That has a lot to do with it."

Improved small grain varieties

Access to improved small grain varieties relevant to a farmer's geographic region or desired markets was the third most selected factor that *helped* small grain farmers' ability or willingness to grow small grains. Those farmers who have discontinued growing small grains and those who have never grown small grains did not commonly report a lack of improved small grain varieties as a barrier, although focus group and interview data suggest that this is due in part to non-small grain farmers' inexperience with small grain varieties. During focus groups and interviews, the issue of genetics came up frequently, and farmers told us that they did not have access to the small grain varieties, especially for organic production, that they need to be profitable.

Modern improved varieties are developed by plant breeders in a process largely external to the farmer, thus we categorize access to them as a structural factor. Improved varieties can help

farmers increase yields and manage disease and toxins from mold and fungi such as vomitoxin and aflatoxin that are particularly challenging in the Upper Midwest due to relatively high levels of rainfall and humidity during the growing season. There was a particular focus on the need for varieties suited to the wetter conditions of the region to compete with farmers in the Dakotas and Canada, where much of small grains are currently grown. A current small grain farmer from Illinois told us:

> I think there's profit to be made [in small grains]. We just need to be looking at different varieties.… I'm not sure that we've really developed wheat for our organic side. The problem with the organic side is that you have no rescue, you can't go in with fungicides, you can't go in with the herbicides, you can't go in with anything like that.… I'd like to see maybe a little better, a little different breeding program.… There needs to be some new characteristics in it. Some new varieties brought out. I mean, we're planting the same oats I did as a kid. You know, 45 years ago.

Due to their limited acres and therefore limited profitability for private investment, small grains in the Upper Midwest are "orphan crops," or crops that receive little attention from the private sector despite their importance to food security. Because of this, small grains remain largely in public-sector breeding programs (Moore et al. 2023; Naylor et al. 2004). Yet, unlike corn and soybeans that have benefited from substantial public breeding support, the public small grain breeders we spoke with lamented that funding is lacking for public small grain breeding programs, a global issue among public breeding programs that has resulted in a decline in public plant breeders and public cultivar development (Knight 2003; Shelton and Tracy 2017). Consequently, many of the more advanced biotechnologies related to plant breeding have not been applied to small grains. Public-sector plant breeders rely instead on more traditional breeding methods that, while producing less costly seed, can take upward of 10 years to bring a new line to market (Alahmad et al. 2022; Shelton and Tracy 2017). More sustained, long-term funding for public plant breeding is needed along with efforts that can speed up the varietal development process at public institutions like the Small Grains Genomic Initiative (American Malting Barley Association 2023).

Still, there was a sentiment among the breeders that varieties developed in the private sector with advanced breeding technologies tend to be seen as modern or cutting edge by farmers and therefore more desirable. Most small grains, however, naturally require fewer inputs (Marshall et al. 2013). Additionally, because small grains are primarily public-sector crops, with little to no investment from the private sector, very few examples of genetic modification exist. This makes seeds and production of these crops generally less expensive, and therefore it is possible that more of the profit goes to the farmer compared to agricultural input companies. This results in a better outcome for farmers' bottom lines. Promoting the low-input and low-cost nature of small grains can help reorient farmers to their inherent benefits compared to corn and soybeans.

Livestock

Results from the correlation network analysis and focus groups and interviews showed that livestock can help drive small grain production. We found that livestock acts as both a structural driver in terms of the availability of livestock markets near the farmer and as an operational driver in terms of whether the farm chooses to have livestock on-farm. Both are due to the synergies between small grain production and livestock: livestock act as a secondary market for grain that does not find a buyer, and small grain silage and straw provide a source of livestock feed and bedding. In this way, farmers "hedge" with livestock to lower the risk of small grain production.

Food-grade production of small grains in the Upper Midwest is risky due to the difficulties of meeting quality grade specifications required by buyers (see *Regional growing conditions* section). A much higher percentage of farmers in the sample (70%) grew small grains for livestock, either for on-farm feed or bedding, sale as feed, or sale as straw, compared to those who grew for food or beverage-grade (38%). Livestock feed markets, on the other hand, have fewer quality requirements and several farmers stated that livestock feed and bedding are the most viable markets in the region. Many of them said that they would

be more likely to grow more small grains if they had livestock markets around them or livestock on-farm.

Livestock, however, has spatially concentrated as crop and livestock systems have decoupled in the United States (Friedma and McMichael 1989). Iowa farmers surveyed by Weisberger et al. (2021) reported that the decline in integrated crop–livestock systems was a major barrier to small grain and forage production. Yet even in areas concentrated with livestock, markets for small grains as feed are no longer common. This is likely because, as discussed in focus groups and interviews, farmers consider small grains as slower to fatten an animal and less palatable compared to corn and soybeans, and making silage with small grains involves more risk than corn and soybeans due to the uncertainty of when to harvest to optimize nutrients. A dairy researcher told us, "Corn is the king, and alfalfa is the queen. And that's what it takes to make a kingdom.… We've created such specialized, very intricate systems that rely on corn and legumes that complement each other in terms of what they give to the animals that it pushed away other possible feeds."

Yet, replacing a portion of corn with small grains in feed rations can lower the cost of the ration and has been shown to support equivalent growth rates and feed efficiencies (Lammers 2017; McGhee and Stein 2020). Echoing Muckey (2018), more research on feed-grade opportunities for small grains should be pursued. Promoting small grains in livestock rations and greater small grain varietal development suitable to livestock feed will help improve their potential as a livestock feed. Moreover, reintegrating crop and livestock production on farms in the region will be key to creating feed markets for small grains and to encouraging small grain production for on-farm use. Encouraging integrated crop–livestock operations can be achieved through more technical assistance and cost share through programs like EQIP, as well as more research and extension on the benefits of integrated croplivestock systems.

Cost share programs

Farmers did not commonly report that cost share programs such as EQIP or CSP influenced their decision-making in surveys; however, correlational network mapping showed that whether a farmer said that cost share for small grains was available to them was strongly correlated with whether they grew them. The latter supports conclusions in most literature on the positive effect of cost share program participation on conservation practice adoption (Fleming 2017; Park et al. 2023; Sawadgo and Plastina 2021). During focus groups and interviews, farmers explained that while cost share programs do not drive their decision-making, the additional incentive helps. A current small grain farmer from Wisconsin explained, "If you got that seed money or that cost sharing or whatever, it definitely helped. Many times, you got to jump through some hoops, but most of the time it's worth jumping through the hoops." Yet, through focus groups and interviews it was clear that cost share programs can be improved to realize their potential on adoption. A current small grain farmer from Minnesota told us: "It's always seemed like there's so much documentation you have to provide [and] so many hoops you got to go through just to do something simple like [enroll in a conservation cost share program]. And it always seemed overwhelming when you sign up for a program such as that." Farmers explained that the application processes must be simplified, greater flexibility afforded to participants, and more funding is needed to support programs.

System benefits

Small grains were historically used in rotations to disrupt cycles of pests, disease, and weeds, and our results made clear that many farmers still appreciate these benefits, and in some cases, it drives their use. A farmer's belief that small grains in rotations improve the health of soils and mitigate risks was strongly correlated with growing small grains. Additional strong correlations found between the belief in the soil health and risk reduction benefits of small grains, and the beliefs that small grains reduce chemical needs and increase yields suggest that many farmers understand small grains as part of a system with multiple benefits. These findings echo other research showing that positive attitudes

toward and beliefs about a practice are associated with adoption (Prokopy et al. 2019). For example, Roesch-McNally et al. (2018) found that farmers with positive attitudes about the climate benefits of diversified rotations were more likely to have diversified rotations.

While it is clear that economic considerations are central to whether a farmer grows small grains, to be adopted it is important that a new crop fit well into existing agricultural systems (Lockeretz 1988). Farmers in the study struggled to make small grains profitable in relation to corn and soybean production; however, some said they continue to grow them "on principle" due to their benefits in a rotation. One farmer from Iowa explained that growing small grains is part their "conservation ethic" to ensure the health of their soils and local waterways. Other farmers discussed the positive impact small grains had on reducing pest and disease pressure and increasing water infiltration.

The benefits to soil health were particularly important to the farmers in our study. Surveyed farmers recognized the soil health benefits of small grains—46% grew small grains at least in part as a cover crop or green manure, 59% said that the reason why they grew small grains was in part due to the soil health benefits (the most selected reason), and 65% said that they believed small grains in rotations improve the health of soils. One current small grain farmer from Illinois said: "I've noticed that when I took this farm over seven years ago, they were not doing hardly any small grains. And I have, you know, really stepped in to do it. And I find, I mean, we're doing less tillage. So, you know, especially in today's market and the price of fuel, everything that's got small grains on it, that soil seems to be much, much looser, a much nicer soil, better seed beds. So, I think we're gaining on the corn and soybean end of it also, gaining some production here."

Thus, while stronger markets for small grains will do the most to incentivize their use, promoting their system benefits may also drive production, especially on marginal land. A researcher we spoke with summed up the notion: "Clearly small grains have lost ground to corn and soybeans in the last century … if you want to advocate for it you're not going to get it back into the system by comparing it in one dimension … you need to put it in a whole system context … this is how you are going to get farmers to say, 'yeah that makes sense.'"

Synergies between small grains and cover crops

Through focus groups and interviews, the unique synergies between cover crops and small grains emerged. Cover crops and small grains can feed into each other in ways that support each other's production. Cover crops act as a gateway to small grain production; once a farmer sees the soil health benefits of a small grain as a cover crop (a crop used to cover otherwise bare soil to reduce erosion, increase organic matter, and suppress weeds) (Bruce et al. 2022), and gains some experience growing them, they will be more comfortable taking the leap to feed or food-grade production. At the same time, small grains in a rotation can act as a "nurse crop" for cover crops; they are harvested early enough in the season to allow time to establish a fall-planted cover crop. Given that using small grains as a cover crop is the second most common use for small grains listed by farmers on the survey, this may be a promising strategy to encourage small grain production. A current small grain farmer from Wisconsin recounted, "The original times that I grew wheat as a dairy farmer was as a cover crop. FSA was pushing it and basically, we had absolutely no intention of keeping it for a cash crop, it was going to be destroyed in spring, but all of a sudden you had a nice crop out there.… Let's see if we can do something with it. And A and B lead to C, and it kind of falls in place."

Rye and barley are two small grains commonly grown as cover crops in the Upper Midwest; however, there are few buyers for these crops. A small grain broker explained:

> There's always a little bit of an oversupply of those two, or lack of a market.… It either goes into the feed market and some of it goes into the beverage industry or the food industry, but the vast majority of it's just grown for a cover crop because there's no market to support it really, or very little.… I actually just think that there needs to be more market development … it's a little bit more about having a concerted effort then for bench-top development and research and development to really go into play. Rye could be used in a number of different capacities than what it's currently used today.

Organic certification

Small grains are a viable and common way to fulfill the extended crop rotation requirement for organic certification and being certified organic was strongly correlated with growing small grains. Without the ability to apply chemical pesticides and fertilizers, small grains are a strong candidate for organic systems as they require less N fertilizer and naturally build fertility and manage pests and weeds in rotations (Marshall et al. 2013). Organic certification is both an operational factor in terms of whether the farmer chooses to pursue the certification, and a structural factor in that the certification requirements decided by the USDA can be expensive and time intensive.

Still, organic farmers struggle to make a profit from their small grains (Baker and Russell 2017). A current small grain farmer from Illinois shared that, "The corn and beans are very profitable, the small grains portion of the operation is where we struggle to make money.… The profitability on the corn and beans is what supports the organic operation, the small grains is what we do pretty much because we are required to have the three-crop rotation." Supporting the growing organic industry would allow more farmers to receive a premium for raising a product with regenerative agricultural practices that include crop rotation.

Additional management

Extending a corn and soybean rotation to include a small grain means more planning and work (which we identify as an operational barrier), especially since small grains do not usually have set input packages nor the same technical or programmatic support (which we identify as a structural barrier). This is especially difficult as most farmers in the Upper Midwest no longer know how to grow small grains. A non-small grain farmer from Illinois encompassed the sentiment we heard across non- and discontinued small grain farmers when he explained,

> I guess you get used to what you're doing sometimes. And maybe a better way to phrase it [is], until what we're doing isn't working might be when we would look to do something different.… We want to be known as good farmers. So, it would have to still fit in that structure that we were getting stuff done timely, so. And it sounds weird, but you're throwing a third thing into the operation because, I know it's not just the planning of it. It's a different kind of spray … it's just a different part of our system and complexity that I don't know if it would work or not.

An agronomist echoed the farmer's thoughts when they explained, "I just feel like one way or the other, corn and soybean production has become the most convenient.… It's still like a level of complexity or inconvenience that [farmers] just don't want to tackle anymore." In addition to market development and cost share incentives for planting small grains discussed above, greater educational outreach to non-small grain farmers via Cooperative Extension and other agricultural professionals is needed to emphasize their low-input, low-cost nature, their benefits in crop rotations, and to promote systems thinking in crop rotation and planning. In addition, farmers must know that it will pay to add small grains to a rotation to take the initial risk of adoption. More research is needed to quantify the economic benefits of diversified rotations that include small grains—the most common response when farmers were asked about research needs during interviews and focus groups.

SUMMARY AND CONCLUSIONS

Adding small grains in crop rotations is one of the most logical ways that corn and soybean farmers can diversify their systems, concurrently reaping a broad suite of agronomic and environmental benefits. Yet, through multiple methods and ways of knowing, we found there are a myriad of interconnected reasons why farmers in the Upper Midwest primarily plant only one to two crops and why diversifying to additional crops, in particular small grains, is challenging. Farmers identified markets and prices as the most important reasons, yet abundant markets and high prices for corn and soybeans did not occur on their own. The proliferation of a minor crop such as a small grain requires a multifaceted approach, including action and collaboration on the part of university researchers, Cooperative Extension, USDA, policymakers, seed companies, grain processors, food companies, farmers, farmer cooperatives, farmer organizations, and commodity groups.

Through this research, we also find that creating our local, daily bread in the Heartland is

not only about food for people. Food-grade production is a strong end goal, creating a higher-value product through which farmers might capture more of the profit if sold locally and closing a loop in our regional supply chains. However, small grains are also a valuable livestock feed and feed the land as an integral part of regenerative, organic agricultural systems with pillars of crop rotation, cover crop use, and integrated livestock at the core.

In the case of policy, it is important to note that while we found that the small grainspecific elements of farm bill programs are less important to farmer decision-making compared to their markets and prices, it would be a mistake to conclude that policies are not important. Supports for marginal crops are less important compared to markets, but farmers in the region rely heavily on these programs for their primary cash crops: corn and soybeans. Without them, their return on investment would be substantially lower some years, making production riskier, and longer rotations with more crops more economically rational. Shifting subsidies to incentivize diversification and eliminating the corn ethanol mandate will go a long way to revalorize longer and more complex rotations.

Moreover, small grains, like most marginal crops, lack widespread advocacy organizations that promote their interests, a broader structural factor not captured in this research that focuses on the farmer perspective. Commodity associations like the Minnesota Wheat Research and Promotion Council and the National Barley Growers Association could be developed in other regions and for other small grains to promote research and development and to advocate for funding for market development and cost share in state and federal policy. Given the lack of acreage for many small grains, a broader, coordinated strategy that advocates across multiple small grains, such as the Maryland Grain Producers Association, may be a promising way to collectively support the small grain industry. Further, regional networks like Main Grain Alliance Colorado Grain Chain and Artisan Grain Collaborative (Midwest) that support value chain coordination to build and strengthen connections may play an important role in advancing the adoption of small grains on the landscape and in the local food system.

Based on our findings, we conclude that to enable strong agricultural markets and support farmers to produce small grains, it will be important to (1) invest in market development, on- and off-farm infrastructure, and improved varieties; (2) level the playing field with corn and soybeans in terms of subsidies and supply mandates; and (3) leverage the drivers of existing small grain acreage—certified organic production, the integration of crops and livestock, systems thinking, and cover crop use. While the order and importance of each is debated, just as there is a need for functional redundancy for ecosystem resilience (Walker 1992), there is a need for "engineered redundance" (Naeem 1998, 39) in the measures taken to change farmer behavior and the system in which it is embedded. Indeed, the gradual growth of corn and soybeans over the last century suggests that it is not one factor that is the key to unlocking wide-scale adoption—rather, several factors that combine to move the needle. Each factor depends on the other to create an enabling environment in which the farmer is willing and able to adopt. Addressing each element shown to impact farmer decision-making should be undertaken simultaneously in an iterative process to ensure that small grains have the same potential as corn and soybeans in the Upper Midwest.

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