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Building cover crop expertise with citizen science in the upper Midwest: supporting farmer innovation in a time of change

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The use of cover cropping, as one element in a continuous living cover approach, has the potential to protect water quality and promote soil health, but overall U.S. acreage in cover crops as well as adoption rates remain low. Research on behavioral barriers to cover crop use indicates a lack of information about locally suitable practices and cover crop varieties, as well as the additional management complexity of cover cropping and a high degree of uncertainty in outcomes, especially in areas with shorter growing seasons. This paper describes the development of a citizen science project on cover cropping in Wisconsin designed to (i) generate more geographically distributed data on cover crop performance in the state; and (ii) build understanding of farmer decision-making around growing practices, barriers, and motivations for cover cropping. Citizen science, as it relies on physically distributed members of the public in data generation, is well established as an avenue for generating environmental data. We engage the approach as a tool for also researching influences on individual behavior and identifying potential leverage points for change, especially on-farm innovation and experimentation. I share project findings regarding cover cropping practices and biomass production, results on motivations and influences for cover cropping, as well as participatory approaches to share those results with farmers. This project also offers more general insights into how the citizen science model can be used to expand understanding of decision-making contexts, and to develop responsive outreach efforts that support participants in taking action.

KEYWORDS
cover crops, U.S. Midwest, agricultural transformation, participatory research, citizen science

1. Introduction – cover cropping and agricultural transformation

This paper shares the case study of an ongoing citizen science effort to improve understanding and use of cover cropping in Wisconsin. "CCROP," or Cover Crops Research and Outreach Project, is a collaborative effort on cover crop research and outreach. The collaboration includes a citizen science element designed to generate more physically distributed data on the practices and results of cover cropping as well as a broader understanding of the context and processes of decision-making by farmers who cover crop, and how best to support on-farm innovation and engagement with environmentally sound practices. Objectives include linking information produced by farmers on their agronomic practices with researcher-produced data from long-term agronomic studies on cover cropping in Wisconsin. Long-term agronomic studies include researcher-led work at the Michael Fields Agricultural Institute in Troy, Wisconsin, as well as the Wisconsin Integrated Cropping Systems Trials (WICST) at UW-Madison, a 24-hectare randomized and replicated experiment evaluating conventional, organic, grazing, and cover cropping systems, and one of the longest running cropping trials and associated databases about sustainable agriculture in the country.

Understanding barriers to conservation practices and how and why farmers overcome them is critical for transitioning to a more regenerative agriculture (Reimer et al., 2012; Blesh and Wolf, 2014; Roesch-McNally G. E. et al., 2018; Roesch-McNally G. et al., 2018). In this paper I describe how the CCROP project identified a lack of locally appropriate cover crop information and developed a citizen science effort to fill that gap. The project also explored the potential of the citizen science model in agriculture to expand understanding of how such data can be useful to farmers interested in innovative practices.

As the impacts of agriculture in both creating and potentially mitigating environmental harm are increasingly part of a broad conversation, so too is the role of farmers as critical agents in responding to that harm (Mottet et al., 2020; Petersen-Rockney et al., 2021). The U.S. food system produces large volumes of food and commodities at low per unit cost but accompanied by severe negative externalities including widespread fresh and marine water pollution, greenhouse gas production, and soil loss through erosion. This is especially notable in the highly specialized intensive corn and soybean landscapes of the Midwestern U.S. (Prokopy et al., 2020; Matson and VandenBrook, 2021). Individual on-farm decision making—about practices such as cover cropping, tilling the soil, and diversifying production—is being scrutinized in the context of a broader conversation on the role of agriculture in providing such public environmental goods as soil health, clean drinking water quality, and carbon capture (Vanni, 2014; Lamine and Dawson, 2018; Burchfield et al., 2022).

CCROP was initiated in 2017 to better understand the current use and conservation potential of cover cropping by farmers in Wisconsin, and to inform policymakers regarding the role of the state in supporting cover cropping as a practice beneficial to water quality and soil health. Advocates of cover cropping—planting a single or mix of plant species along with, or following, a cash crop—promote potential multiple benefits including building soil fertility, preventing soil compaction, erosion, and nutrient runoff from fields, boosting biodiversity by supporting pollinators and other wildlife, managing weeds and insect pests, as well as building ecological resilience in the context of climate extremes, including droughts and flooding. With 75% of the U.S. Midwest's agricultural land in corn and soybeans, cover cropping offers a tool in shifting current conventional agricultural practice toward a more holistic management approach that emphasizes continuous living cover. More consistent plant coverage on agricultural fields helps to store carbon, build soil health, and reduce erosion leading to water pollution, especially nutrient loading of waterways, which in turn threatens drinking water and the health of streams, rivers and ultimately, the ocean (Cates et al., 2018; Cates and Jackson, 2019). Cover cropping, as it requires more complex management approaches, can offer an "on ramp" to other site-sensitive production practices for farmers in intensive production systems (Roesch-McNally G. E. et al., 2018; Roesch-McNally G. et al., 2018; Thompson et al., 2021).

According to the 2017 USDA agricultural census, the percent of U.S. cropland planted with cover crops increased by 50% between 2012 and 2017, from just over 10 million acres to more than 15 million. But those acres still only account for about 4% of the nation's total cropland (Dunn et al., 2016). Nationally, cover crop adoption rates increased from 3.4% in 2012 to 5.1% in 2017 but vary a great deal across and within states as they are influenced by policy, environmental conditions, and other drivers. For example, Maryland, which has been heavily promoting and subsidizing cover crops for over a decade, especially within the Chesapeake Bay watershed, had an adoption rate of about 33% in 2017, while rates declined in other states. Cover crop adoption in Iowa is more common in the southeastern portion of the state where soils have lower organic matter and higher erodibility (Wallander et al., 2021). The diverse drivers of adoption suggest a dynamic and complex mix of benefits, costs, and policy influences on cover cropping decisions.

USDA estimates of cover crop use on cropped land in Wisconsin are 6% to 10% of cropped acres in most counties, with 10%–15%, and even over 15%, in a "hotspot" of central to western Wisconsin counties (Siefert, 2017; Wallander et al., 2021). Cover crop adoption rates in Wisconsin and Minnesota have not kept pace with Illinois, Indiana, and Ohio, and farmers in these more northern states are also more likely to stop using them (Seifert et al., 2018). Research on the biophysical impacts of cover cropping complicates easy conclusions about the benefits to soil health and water quality, especially across the wide range of conditions in which farmers grow (Myers et al., 2019; Vincent-Caboud et al., 2019; Sanford et al., 2022). Especially in the more northern areas of Wisconsin, a shorter growing season challenges farmers to plant a fall cover crop and for it to establish the biomass needed to prevent erosion and produce other cover crop benefits.

Thus, cover crop performance varies across different growing conditions, and on any particular farm a mix of variables impact "success" or "failure." When it comes to cover crop management, one size does not fit all, or even the same person year to year. In a series of focus groups with corn belt farmers in Indiana, Iowa, and Illinois about barriers to conservation practices, Ranjan et al. (2020) reported that cover crops were not particularly popular, both because of the complex nature of the practice, and also due to dissatisfaction with the continuity of outreach and resources available to support sustained use of cover crops. In addition, decision-making path dependency and technological lock-in create barriers for farmers, especially those invested in intensive production systems (Gould et al., 2004; Roesch-McNally G. E. et al., 2018).

For some sectors like organic agriculture, including cover crops in rotations is a necessary form of soil fertility. But for many conventional farmers the uncertain outcomes and additional variables to manage, including the necessary investment of cost and time to experiment and fine tune them for each field, create multiple challenges in adding cover crops to a rotation.

Despite these challenges, however, benefits of cover cropping are well established (Myers, 2023), and the practice is increasingly encouraged and incentivized, promoted and funded via a variety of federal, state, and regional conservation programs (Siefert, 2018; Hellerstein et al., 2019; Wallander et al., 2021). In a 2021 address before Congress, President Joe Biden specifically mentioned "farmers planting cover crops" to capture carbon. A number of state government and private incentive programs support farmers in cover cropping; funding of federal and state conservation programs is highly correlated to cover cropping rates (Ramirez et al., 2015; Zhou et al., 2022). Illinois, Indiana, Iowa, and Wisconsin in recent years have initiated programs to offer crop insurance rebates on fields with cover crops.

2. Identifying information gaps on cover cropping in Wisconsin

Interest in cover crops among Wisconsin farmers is strong despite aforementioned barriers. In 2020, the CCROP collaborative surveyed agricultural educators around Wisconsin to learn more about how educators viewed farmer interest, knowledge deficits, and perceived barriers to the use of cover crops in the state (Krome and Ingram, 2020). Of the 90 educators who responded, 40 were county conservation specialists, 8 were county ag extension agents, 7 were farmer-led watershed group collaborators with the others representing various university, agency, and crop consultant positions. We had roughly even representation in all quadrants of the state with 5 people reporting working statewide. Over 95% reported providing cover crop information to farmers in their area in the past year, with people receiving from under 5 to over 20 inquiries. In terms of preparedness, some 62% of 89 respondents indicated they did *not* have sufficient locally specific information on cover crops to answer farmers questions, but this differed according to location. Respondents working in the south and west of the state were more likely to respond saying they had the locally appropriate information to answer questions, while people in the north and east were more likely to report lacking appropriate information (86% and 65%, respectively; Figure 1). Respondents who reported covering the full state or multiple areas (17) were 82% more likely than those working in single quadrants to indicate that they lacked sufficient locally appropriate information to answer farmers' cover crop questions.

A follow-up conversation about the survey results between members of the CCROP team and a subset of county conservationists offered specifics on what kinds of information farmers are lacking, as well as the complexity of decision making around cover crops. Participants noted that cover crop equipment setup is an area where they struggle to provide information. They identified producer-led groups as especially effective in providing equipment-related information, especially in explaining planter components, how to repurpose equipment, and working on a tight budget. One participant commented that information on cover crops targeted to farmers can be "fairly technical," presenting an additional barrier to more risk averse farmers. Farmer testimonials, including videos, may help make cover crops more accessible and provide a farmer-to-farmer perspective. Another participant noted that adopters of cover crops have encountered challenges which have left others hesitant to try cover crops—aerial seeding failures were specifically mentioned.

Participants in the conversation also shared that while costs associated with cover cropping is often raised by farmers and educators as an issue, they have effectively responded to such concerns by presenting cover crops as one element in a "systems approach" to overall farm sustainability. This observation echoes the qualitative results from farmer focus groups held by Roesch-McNally G. et al., (2018), who reported that for farmers who viewed challenges in implementing cover crops as creative management opportunities and took a trial-and-error approach, cover crops were just one piece in a larger dynamic "whole system."

With these Wisconsin survey results in mind, the CCROP collaborators launched a citizen science effort in 2020 to respond to the lack of locally appropriate information about cover crop

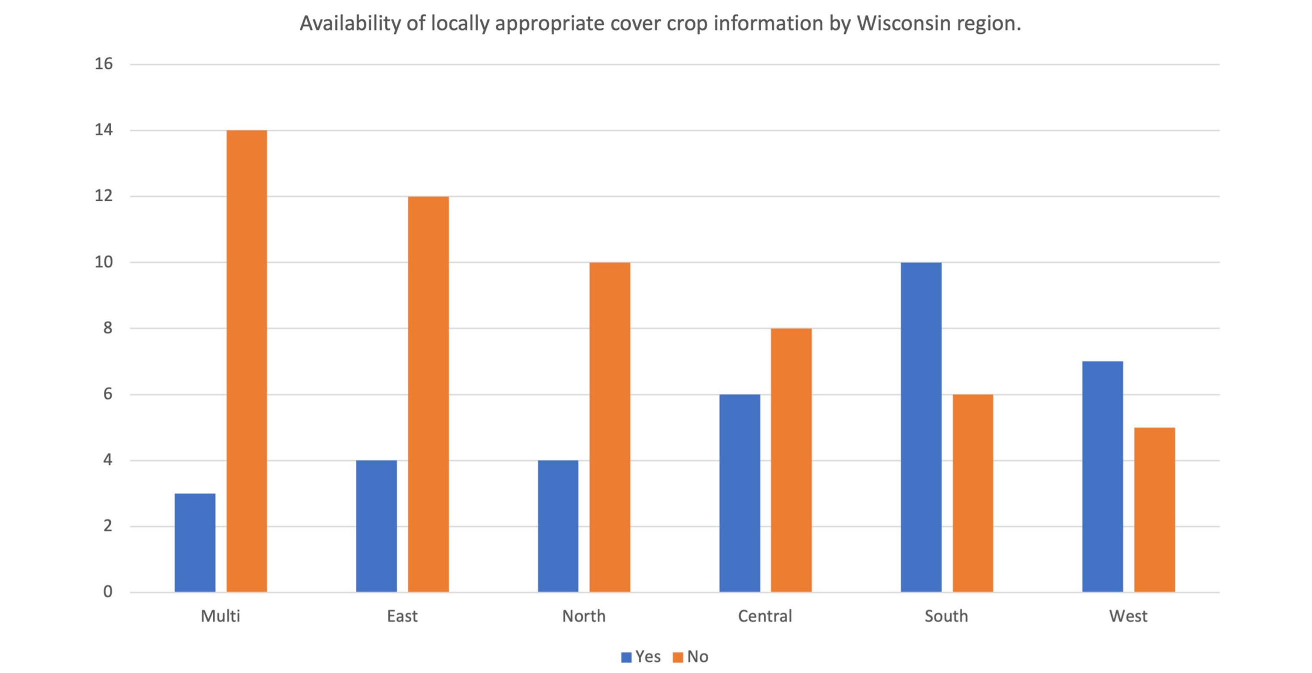

FIGURE 1
In a 2020 survey, Wisconsin agricultural educators (y axis is number of respondents out of 90) replied to a question about whether they felt they had sufficient locally appropriate information about cover crops to respond to farmer inquiries. Educators in the north or east, or who covered multiple parts of the state were far more likely to respond that they lack sufficient locally appropriate information.

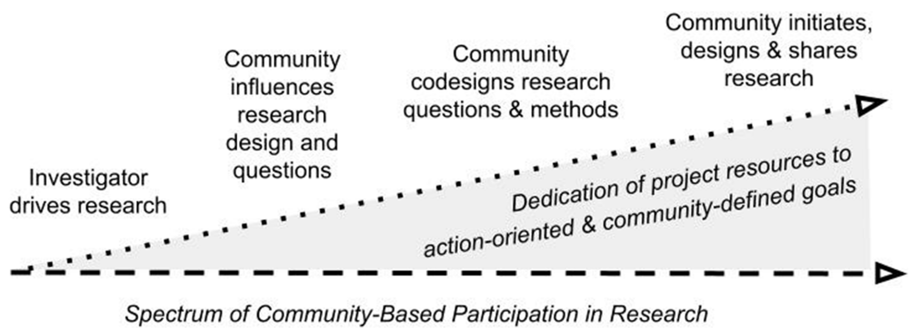

FIGURE 2
Participation and action continuum (adapted from Israel et al., 2005). The involvement of community members in projects at the left end of the spectrum can be limited to supplying data. In more community-driven and action-oriented projects, citizens help define issues and questions, and collect and analyze data in collaboration with researchers. The more dedicated the action focus, the more important participation becomes.

performance. We also sought to use the citizen science method to learn more about the context within which Wisconsin farmers were navigating the complexity of cover crop decisions.

Before turning to our methods, survey results, and discussion, I briefly review literature on the particular promise of citizen science in agricultural settings. This context is useful for understanding how the citizen science model can work not only as a data gathering tool but also as a method to support farmers in taking action, specifically to experiment with more complex environmentally responsive practices.

3. Agricultural citizen science

Thanks to the spread of communication networks and affordable connecting devices such as cell phones, the use of citizen science is expanding, especially in the environmental sciences (Strasser et al., 2018). Generally speaking, citizen science is the voluntary participation of members of the public in conducting scientific research. Although agriculture has seen relatively fewer such projects, citizen science engaging with farmers is on the rise, offering an opportunity to reflect on the unique potential of farmers as citizen scientists, as well as on the element of participation as it is realized in different projects (Ryan et al., 2018; Kimura and Kinchy, 2020; Mourad et al., 2020; van de Gevel et al., 2020; Ebitu et al., 2021).

Citizen science efforts fall on a spectrum of participation. Projects can range from a narrow engagement with participation that connects with citizens as primarily suppliers of data within a research framework defined by an external university-based researcher, to a much more collaborative and community-instigated research effort in which citizens define a research agenda and methods. Community-led movements have initiated important research—asking new questions and producing knowledge that challenges orthodox views (Gaventa, 2002; Ingram, 2007; Strasser et al., 2018).[1] The spectrum includes a range of models for coproduced research design and knowledge creation (Harrison, 2011; Kasperowski et al., 2017; Ottinger, 2017).

A distinctive feature of the participatory nature of citizen science is the centering of new knowledge as it leads to action and application, and generally speaking the more participatory a project, the more action-oriented the results (Figure 2). Alan Irwin (2015) notably described citizen science as an avenue by which publicly funded research can be held accountable to the public good. Citizen science projects can affirm and build expertise outside of academia and be avenues via which academic expertise is made available to public concerns. Irwin also observed a potential connection between citizen science and collective action, observing how citizen science projects have the potential to help build alliances between groups and to "catch the attention of different parties and draw them in in a relatively sustained fashion," (Irwin, 2015, p. 36). This promise, as it links knowledge generation to collective action, expands significantly on a more limited notion of citizen science as an individually oriented educational tool and avenue for building support for the scientific endeavor.

Farmers' daily work making land management and agricultural production decisions can be understood as ongoing experimentation, generating "grounded expertise" (Bendfeldt et al., 2021). Strasser et al. (2018) have identified something similar in the "embodied" and "situated" knowledge resulting from personal experiences of community members involved in citizen science. Reviewing the literature on farmer adoption of conservation practices in the U.S., Thompson et al. (2021) note that most studies treat adoption as dichotomous—a farm has either adopted a practice or not. Citing Pannell et al. (2006), they argue for conceiving of farmer engagement with conservation practices as a "continuous learning process," which includes an always ongoing series of activities gathering information, experimenting, and scaling up or dis-adopting.

This perception of farmers as continuously generating knowledge from ongoing experimentation, gathering data, and applying that information in trial-and-error suggests the appropriateness of an action-oriented citizen science effort in an agricultural context.

1 Cooper et al. (2021) make a clarifying distinction between citizen science and "community science." They write: "The term community science should be reserved for projects that focus on local priorities and local perspectives and are able to maintain the locus of power in the community [such that] authority, power, and funding rests with communities."

Knowledge "coproduction," as it combines academic and nonacademic expertise in defining as well as solving problems, is increasingly central to sustainability research, and prioritizes action-oriented, context-based, and interactive knowledge generation (Norström et al., 2020), all of which can be featured in citizen science approaches.

Such action-oriented approaches to citizen science can also offer a correction to a "deficit" model in which farmers are viewed as passive, even reluctant targets of individually focused informational and behavioral change efforts (Schneider and Ingram, 1993). In a study of the use of climate forecasting tools, for example, Feldman and Ingram (2009) observed a lack of engagement by farmers even as they were facing new challenges related to drought and climate change. The authors suggested that farmers were not taking advantage of the tools at least in part due to a one-way delivery of the information—a "loading dock" model—and argued for the need for the sharing of new information and tools via "knowledge networks that are recursive, interactive, and end-to-end useful." People operate within different "decision spaces" with both time and space dimensions, and delivery of information outside of such spaces do not do decision makers much good, they observed.

Understanding individual decision spaces and social networks is key to the "salience, reliability, and trust" of data (Cash and Buizer, 2005; Carolan, 2006; Silva and Tchamitchian, 2018; Jakku et al., 2019; Anderson et al., 2020; Rust et al., 2022). Farmers need information in a form and timeframe that fits their decision spaces as land managers, and when they are faced with risky decisions, hearing from trusted sources is important. Research on farmer attitudes about behavior change reveals the extent to which farmers themselves understand how their individual decisions are shaped by their social networks as well as cultural, policy, and economic contexts (Ranjan et al., 2020). Thus, our goals for the citizen science project included not only linking information from farmers to the state's cover cropping databases but also learning about farmers' decision-spaces—identifying key information networks and learning how to supply that data back to farmers in ways that support them in taking action, specifically supporting ongoing local innovation with cover crops.

4. Methods

With these goals in mind, we launched a hybrid citizen science project in 2020 to collect cover crop information supplied by farmers supplemented by project staff gathering biomass samples. We sought to learn about perceived barriers and how they were overcome, about trusted sources of information, and to identify potential avenues for supporting others interested in cover cropping. Our citizen science approach also involved a participatory element: gathering and using farmer feedback in survey design, supporting Extension staff in networking with farmers, as well as producing individualized reports, annual summaries, and opportunities for farmers to share results with other farmers. We developed a 35-question online survey via which farmer participants could share information. The survey questions were formatted to allow comparison to cover crop databases from Michael Fields Agricultural Institute and WICST. We included questions about timing, rotations, soil texture, cover crop species, manuring, and tillage. We also asked about seeding methods, rates, and costs as well as termination methods and timing. We included open-ended questions too, asking for example: "Please share any other details regarding establishment, growth or management of cover crop species. Any interesting experiments, failures, equipment challenges?"

The survey collected background information including number of years' experience with cover cropping, percent of farm in cover crops, and whether or not farmers were interested in expanding that amount. The survey included a number of qualitative questions aimed at building our understanding of the context of farmers decision making regarding cover crops. We relied on a Likert scale, asking farmers to select and rank as more and less important a list of sources of information on nutrient management and cover cropping, for example, on motivations for cover cropping, and potential positive influences. Potential influences we provided in our survey question included crop insurance breaks, additional information on equipment, cost reductions for the next cash crop (i.e., due to N credits or weed suppression; more time to experiment with cover crops; or support from additional county Extension personnel.) We also asked several open-ended questions; for example, if we had missed any significant motivations and their opinion of the survey itself as it attended to important considerations in cover cropping.

The comments sections generated rich data, which we supplemented with two extended interviews in 2022 with farmers we identified via farmer-led producer groups who were willing to share their cover crop experiences, ideas about how more farmers might begin using cover crops, and impressions of the survey. Our inductive content analysis for the qualitative data involved manually assigning labels, such as "cost," or "grazing," which we could quantify and out of which we identified key themes. Additional farmer interviews would be required to undertake narrative or discourse analysis but the two we pursued as well as a number of informal conversations were useful in iteratively verifying labels and identifying emergent themes. For example, from comments we were able to take the theme "cost" and identify subthemes related to time management, cost of seed, cost of equipment, and yield impact. We also cross-tabulated qualitative responses, for example, examining whether years of experience or location were correlated with more or less interest in expansion or need for information.

Participants also agreed to coordinate a November field visit with one of our collaborators from UW-Madison's Nutrient and Pest Management program to collect a fall biomass sample from a chosen cover cropped field. We choose fall biomass to assess the cover crop growth of all cover crop species, including those that will not over winter in Wisconsin, like oats, forage peas, and berseem clover. With limited time and monetary resources sampling in the spring is not yet an option. An in-person visit in the fall provided project staff an opportunity to visually assess the state of cover crops on different farms around the state, and in several cases to talk briefly with participants. We randomly sampled aboveground cover crop biomass from three 0.5-m^2 quadrats in each field. Within each quadrat, we used a gas-powered Stihl model 87 hedge trimmer to cut plants at the soil surface. Any weeds present were not separated from the samples. Samples were then dried at 49°C (120°F) for 2 weeks and weighed. We followed up with each farmer participant with their personal biomass estimate, along with a copy of an annual report sharing our general findings (Ingram et al., 2022).

Several strategies contributed a participatory element into our methods: (i) We asked respondents to identify relevant issues we missed and what new questions they might like to see, and then

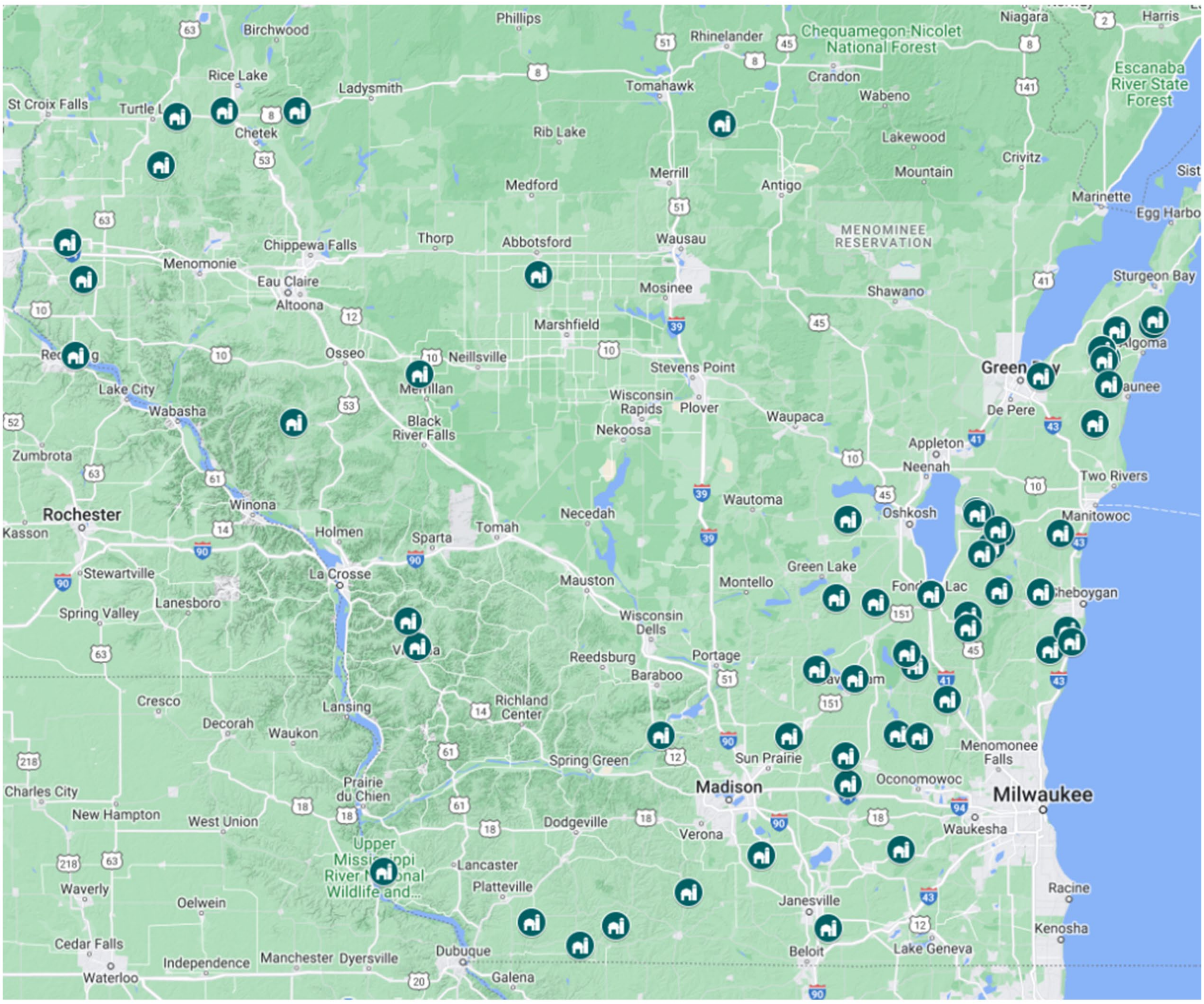

FIGURE 3
Locations of farmers participating in a cover crop citizen science effort in 2022. Farmer-produced data on cover crop practices are helping fill gaps in locally appropriate cover crop knowledge, especially needed in the eastern and northern parts of the state.

adjusting our survey accordingly for the following season. We also asked producers to review drafts of the survey. (ii) On the survey we asked farmers to identify their largest cover crop information gaps and concerns, which we then shared with Extension staff and other researchers via our annual report. We informally asked growers about the usefulness of the report. (iii) We supported communication about this project both by and between growers, aiming to build a self-awareness among participants of others engaged in a variety of cover cropping practices and experimentation. On the spectrum of community-based participation, this project falls between community "influencing" research design and "co-design" research questions and methods (Figure 2).

We also pursued participation via relationship-building with our citizen science participants, including project staff visits to farms and issuing individualized reports with participant's biomass analysis results. An annual report written for farmers was shared widely via Extension networks. We also supported two participants in presenting about their cover crop experiences at a statewide cover crop conference and produced three webinars aimed at growers, agricultural educators, as well as other researchers.

Numbers of participants in the program are low compared to many conventional citizen science efforts, in part limited by project staff time to collect biomass samples but also by the complexity of our survey data and our goal of building the participatory element informed by that data. The number of participants has grown over time (more than doubling), and future goals for the project include augmenting with a spring biomass sample collected by participants themselves. In 2020, 15 farmers around the state participated in the survey, recruited via the state's producer-led groups as well as extension and other agricultural educator networks. In 2021, 26 farmers located around Wisconsin joined, with 5 of them repeats from the previous year. The project launched a third season in 2022, with over 58 signups around the state, just under a quarter of them repeat participants (Figure 3).

5. Results

In response to farmer interest in a contextual presentation of biomass results, our annual reports include a table identifying county, previous crop, cover crop species, planting method and resulting biomass (Table 1). We are currently working on producing an annual report from our 2022 data including generating an online map allowing farmers to see other participants in the same or nearby counties and providing information such as the crop previous to cover cropping in the field.

Farms surveyed in 2021 established cover crops following corn grain and corn silage, soybeans, and winter wheat. Of the 23 growers who reported species of cover crops used, 10 planted a cover crop mixture of 3 or more species. Mixtures tended to contain a grass, brassica, and legume with the most common species being crimson clover, red clover, oats, forage/field pea, and radish. Cereal rye, planted as a single species or with one other such as radish or oats, was planted as a cover crop on 8 of the 23 farms.

In terms of nutrient management and tillage, 16% (4) of responding farmers performed tillage and applied manure prior to establishing cover crops; 60% (15) of respondents used a drill to establish their cover crop, 4 farmers broadcast-seeded with no incorporation, 3 overseeded using aerial methods, and 1 used frost seeding (an option we added after receiving suggestions to do so the previous year). Manure was applied after cover crop planting on 32% (8) fields. Manure application rates ranged from 1.8 to 18 metric tons ha^{-1} of box manure (>20% DM) and 17,034 L ha^{-1} and 49,210 L ha^{-1} of liquid manure (4%–12% DM).

These data begin to provide needed information on local practices and experiments around cover cropping in more areas of Wisconsin. Farmer-provided data included information on cover crop species and contextualized with information about planting dates, nutrient management, and tillage, as well as challenges encountered.

Our 2021 survey respondents had a diverse range of years of experience with cover crops, ranging from 1–3 years to over 10 years. In 2021, cover crop acres planted by each farmer ranged from 10 acres to over 2,200 acres, representing from under 10% to 100% of all acres farmed. 80% of respondents said they'd like to expand the number of cover cropped fields, with 8 of 26 respondents already planting cover crops on at least 80% of all acres they farm. Three top incentives for cover cropping included reducing input costs for the next cash crop, for example, via nitrogen credits or weed suppression; cost sharing programs; and crop insurance breaks.

Most trusted sources of information for nutrient management were Agronomist or Certified Crop Advisor. For sources of knowledge about cover cropping, most respondents listed personal experience first, perhaps an indication of the demand to tailor cover cropping for any particular location, as well as the relative lack of locally sourced information and experience. Agronomists, UW Extension, and farmer-led networks were trusted sources of outside cover crop support (Figure 4). Interestingly, peers and other farmers were low on the list, another indication that experience with cover cropping remains low among many farmers, and that for many of our participants, farmer-to-farmer communication is happening via organized groups like the farmer-led networks. Most respondents selected or wrote in multiple sources.

Respondents selected from a list of "motivations" for cover cropping with most respondents selecting improving soil structure, organic matter, water quality, field trafficability, and weed suppression. If respondents said they were interested in expanding their cover-cropped acres, they were asked about "main barriers." "Time" was listed by half of those growers as a main barrier, with several clarifying that the season is too short following corn and soybeans, that it is "difficult to get covers in early enough," and they have a "narrow planting window." Other growers noted cost of seed as a barrier, as well as equipment challenges including irrigation to get covers established, too few planes available for aerial seeding, needing guidance technology (GPS) to plant corn into a green standing cover crop, and that a 15 foot no-till drill was too slow.

Our survey comment section, along with follow-up conversations with participating farmers illuminated how farmers were continuously experimenting with cover crops. For example, one survey respondent with 4–6 years of experience working with cover crops and interested in expanding his cover cropped acres, commented: "cold spring in 2022, rye took a very long time to begin growing. It wasn't until the first week of May that it even looked like any survived the winter. I let it grow an extra week while I planted other fields. The neighbor harvested the oats/rye forage in late fall. I plan on not doing that again."

One of our interviewees, who has cover cropped for over a decade, described the challenges of his first attempt at cover cropping, "it was tillage radish, did it half-heartedly and nothing grew. I got back what I put in [with that experiment]. So next year I got out the seeder and was more successful." Our second interviewed farmer's story offers another example of how cover cropping as an always ongoing learning process, as well as the importance of equipment: "First year I killed off all the wheat. So second year I had windrows of wheat super thick and nothing would grow. So then sprayed it, and we spread it or raked it up. We still are now testing a spreader on the back of our combine to do a better job. The rear of the combine is a big deal to get residue to spread evenly. If you have a thick mat behind it, affects the corn next year."

Our results also provided information on social networks informing and shaping farmer's initial and ongoing decision-making about cover crops. For many, Wisconsin's state-supported producer-led watershed networks, which have tripled since 2016 from 14 to 43, were a valuable source of support (Figure 4), although one that does take time as our second interviewee emphasized: "For me it was the producer led network, absolutely. Taking the time to go to the meeting and talking with other farmers there. Especially after the event."

He also described the importance of the supply chain in creating opportunities for farmers to learn from one another: "I learned from my seed dealer, but not directly. When Pioneer hosted a farmer thingy, one farmer at a breakout session there was spinning out rye on thousand acres. I thought if he could, I can."

Our first interviewee, in describing the process by which he initially explored cover cropping, revealed the diversity of actors influencing his decisions: "I started taking control of my agronomic planning … instead of hiring a consultant I taught myself on how to do it: I can read about it online, I can watch a video on YouTube, recordings of field days, and hear farmers speaking about what works and what does not. My county agronomist started sharing info on cover crops with me … And my dad and my wife allow me to decide what to do. They've never said do not try something new."

Along with a better understanding of the dynamic, ongoing nature of cover crop decision making we also gained more perspective on "time," as a barrier. It can refer to the short growing season in the upper Midwest, or the constrained circumstances of a farmer in terms of taking risks to try new things. Our second interviewed farmer explained, "My son is too busy to go to those [producer-led] meetings. In my area I think of 4–5 young farmers all doing over

TABLE 1 Cover crop management and biomass production throughout Wisconsin during the 2021 growing season.

County	Previous crop	CC species	Planting		CC biomass			Precip (mm)	GDU[1]	CC termination
			Method	Date	Date	Metric tons DM/ac	Std err			
Grant	–	Annual ryegrass	Broadcast	18/9/2021	16/11/2021	1.2	0.0	142	898	Plant green
Green		Red clover	Frost seed	20/2/2021	16/11/2021	2.1	0.3	597	5,404	Plant green
Iowa		Multi-species mix	Drilled	24/8/2021	05/11/2021	2.7	0.2	208	1,501	Early, herbicide
Jefferson		–	Drilled	20/8/2021	03/11/2021	1.0	0.1	198	1,719	Plant green
Lafayette	Corn grain	Cereal rye, radish	Interseed	26/8/2021	16/11/2021	1.0	0.1	129	1,538	Early, crimp
Lafayette		Multi-species mix	Drill	1/8/2021	–	–	–		–	Plant green
Rock		Cereal rye	Interseed	13/9/2021	26/10/2021	0.6	0.0	155	963	Plant green
Trempealeau		Annual ryegrass	–	15/10/2021	01/12/2021	0.6	0.1	71	257	Plant green
Winnebago		Multi-species mix	Broadcast	17/9/2021	10/11/2021	1.3	0.4	46	922	Plant green
Jackson	Corn silage	Cereal rye	Drill	5/10/2021	09/11/2021	1.8	0.4	25	451	Graze
Manitowoc		Barley, winter wheat	Broadcast + Inc.	18/9/2021	10/11/2021	0.9	0.2	112	810	Plant green
Washington		Cereal rye, oats	Drill	19/8/2021	–	–	–	–	–	Winterkill
Winnebago		Cereal rye	Broadcast	10/9/2021	–	–	–	–	–	Plant green
Vernon	Forage sorghum	Multi-species mix	Interseed	10/9/2021	05/11/2021	0.8	0.1	66	939	Plant green
Green	Soybeans	Cereal rye	Drill	15/10/2021	–	–	–	–	–	Graze
Marathon		Multi-species mix	Broadcast	13/7/2021	09/11/2021	0.9	0.1	414	2,623	Plant green
Polk		Cereal rye	Drill	24/9/2021	9/11/2021	1.2	0.3	79	632	Plant green
Rock		Oats	Drill	30/9/2021	26/10/2021	0.7	0.1	145	531	Winterkill
St. Croix		Cereal rye	Drill	10/10/2021	10/11/2021	0.0	0.0	20.3	214	Plant green
St. Croix	Vegetables	Multi-species mix	drill	15/9/2021	09/11/2021	1.6	0.2	58	796	Early, crimp
Barron	Winter wheat	Multi-species mix	Drill	14/8/2021	09/11/2021	1.9	0.3	203	1,741	Plant green
Dodge		Multi-species mix	Drill	14/8/2021	09/11/2021	0.9	0.1	203	1,741	Plant green
Fond du Lac		Multi-species mix	Drill	17/8/2021	09/11/2021	0.6	0.0	224	1,590	Winterkill
Jefferson			Drill	26/7/2021	03/11/2021	2.5	0.1	307	2,513	Plant green
Pierce		Multi-species mix	Drill	17/8/2021	09/11/2021	1.4	0.1	224	1,590	Winterkill

[1]Growing Degrees Units; base 4.4°C (40°F). Average biomass production was 1.36 metric tons (1.5 US tons) DM/ac.

1500 acres, so time for them to learn is valuable. I do not think an agronomist or a seed dealer or even the coop is going to persuade them cuz if it fails, they'll take the blame. So, they are very careful. I do not know about the incentive. But if you try and fail, it's hard."

In feedback on our reports and interviews, farmers emphasized the importance of narrative context, literally asking for "the story" accompanying the data. Given the range of variables in any cover crop approach, it is very difficult to compare data year to year. Farmers stated they need to understand biomass yield in the context or previous crop, for example, as well as tillage, fertility, and seeding method. As our first interviewed farmer explained: "For me the data means nothing without the story behind it. [In your reports] you are doing a pretty good job in terms of giving us county, precipitation, what crop preceded, what tillage, when it was planted, soil type, how did they feed it. Do not give me a bunch of numbers without the why behind them."

6. Discussion

Many of these results about the challenges of cover cropping will be familiar to both growers and researchers. This citizen science approach is augmenting what is known with a more localized understanding of what cover crops are being experimented with, and building awareness among growers and others about ongoing practices and specific methods with which farmers are experimenting with cover crops. As described in the introduction, a number of incentive programs have championed cover crops to promote their adoption as a way to build soil and protect water quality. In addition, more Wisconsin farmers are aware of cover crops as a way to mitigate some of the challenges associated with climate change. The last two decades have been the warmest on record in Wisconsin, and the last decade has been the wettest (WICCI, 2021). Growers around the state are experiencing extreme rain events, groundwater flooding, declining snow cover, winter thaws, and more frequent extremely hot days and droughts. While we have not yet specifically surveyed growers about climate change as a motivation to use cover crops, we did observe that at cover crop conferences and in our survey comments section, farmers mentioned the benefits of cover crops to include earlier access to flooded fields in spring, for example, as well as protecting soil structure and preventing erosion and soil loss in heavy rains.

In response to farmer interest in contextualized knowledge, our annual report supplied back to participants included a table

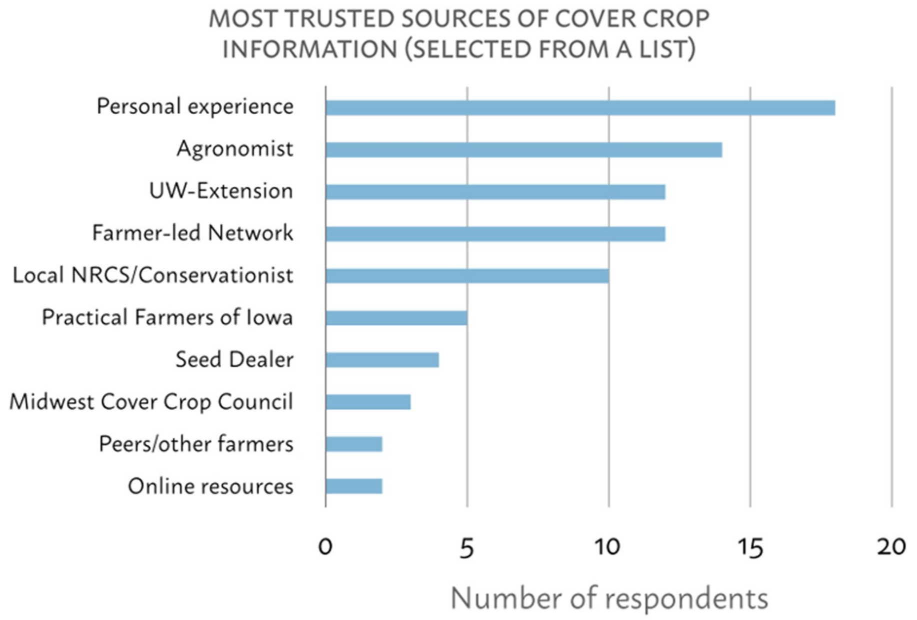

FIGURE 4
For trusted sources of information about cover cropping most 2021 respondents chose "personal experience," with other sources including Agronomists, UW Extension, and farmer-led networks. Written in sources included books, OGRAIN, Michael Fields Agricultural Institute, Wisconsin Discovery Farms, and Iowa Learning Farms.

identifying county, previous crop, cover crop species, planting method and resulting biomass (Table 1). Future plans include developing an online interactive interface allowing participants to access map-based visualizations of the cover crop data they are helping generate. Data visualizations will be accompanied by videos and quotes from our farmer interviews as another contextual element. We plan on testing the interface with farmers, conservation agency staff, agronomists, and others to confirm the level of interest and to fine tune an accessible, effective sharing of information that participants will find useful and actionable within their decision spaces (Feldman and Ingram, 2009).

Other strategies in our participatory approach included using farmer feedback in improving our survey—adding questions related to termination, additional options such as frost seeding, and a question asking what it might take for growers to "stop using cover crops." We also sought farmer input on technical challenges. We were able to provide resources for some of these challenges, and included links and a bibliography in our final reports. Other challenges require additional research, however, and we have shared these in presentations to research colleagues and amended the survey to inquire further; for example in more specific questions about equipment challenges. In response to interest from participants wanting to use cover crops as forage, we added a forage quality component to our most current sampling protocol.

Many of the comments from our participants were aimed toward other farmers. Seeing this as a network building opportunity, we compiled and shared comments in our annual reports and presentations so growers might see how their own interests and concerns were shared by others. As many have observed, farmers enjoy learning from others like them, and are more likely to trust the information in contexts where they can observe how a farmer is putting new techniques into practice. We supported two of our participants in presenting their experiences at the Wisconsin Cover Crop Conference in 2022 and are gathering videos and additional narratives from participants.

Our results resonate with Thompson et al. (2021) and Pannell et al. (2006), who argue for conceiving of farmer engagement with conservation practices as a "continuous learning process." The survey comments and interviews reveal how cover cropping involves an always ongoing set of activities: gathering information, experimenting, scaling up, or dis-adopting. Thus, while our citizen science project delivers annual "results" about cover cropping practice, equally important is the generation of awareness within the farmer research network of what kinds of experimentation and practices other farmers are engaged in, especially in similar locations and farm systems. These activities also point to the importance of continued policy, education, and networking efforts to provide a diversity of expertise and a continuity of support (Ranjan et al., 2020). Our outreach to researchers, educators, policy analysts, and sustainable farming advocates is motivated by our understanding of the need to build a diverse and reliable knowledge network supporting farmers in experimenting and engaging with cover cropping and other practices related to continuous living cover.

One clear limitation to generalizability of our findings is a self-selection bias towards farmers already interested in and using cover crops. Our results provide the most insight into the challenges of famers who are already experimenting with cover crops in their crop rotations, or who are otherwise exploring options for more sustainable practices (although the shared challenges do suggest why some farmers might stop using cover crops). Through our online survey and follow-up interviews and conversations, however, we did inquire about how farmers transitioned to new practices and what they saw as general barriers for other farmers.

7. Conclusion

Knowledge coproduction between researchers and farmers, as it generates needed agricultural information and supports on farm innovation is critical to supporting producers in developing more environmentally sustainable and resilient practices and surviving expanding uncertainties related to climate and markets. Bendfeldt and colleagues argue against an overemphasis on essentialist "best practices" and technocratic problem-solving in food systems research, stating, "The construction and expansion of farmer knowledge are not linear but rhizomatic and mycorrhizal in quality; therefore, scholar-practitioner responses to understanding and engaging with farmer knowledge systems should be amenable to a diversity of culturally dynamic systems of knowing that embody socio-eco relations and networks" (2021, p. 138).

We developed a hybrid citizen science project to respond to an information gap in locally suitable cover crop information, and also to learn more about farmer knowledge networks, and the specifics farmers' decision spaces as they engage in cover cropping. Objectives included filling the knowledge gap with the participation of Wisconsin farmers, and then sharing that information in formats supportive of farmer action. Farmer-supplied data contributed to a more robust data set on cover cropping in Wisconsin, especially in the eastern and northern areas of the state. Farmers shared information on cover crop species selection, fertility methods, seeding methods, and tillage. Project staff visited farms to gather biomass samples in the fall. Qualitative questions in the citizen science survey sought information into challenges and perceived benefits of cover cropping in Wisconsin, as well as insight into how farmers might best consume new information on cover crops. We gathered specifics on the complexity of farmer decision making on cover cropping in the state and gained a better sense of ongoing experimentation and adjusting in response to weather and in the context of diverse growing systems. We built in participatory elements to our research effort including feedback on our own survey instrument and sharing data back to participants about their own results as well as the cover cropping practices around them. One goal is to create an awareness of an informal innovation network of Wisconsin farmers working with cover crops in diverse contexts. Results also emphasize the presence of a diversity of influential actors in the cover cropping decision space, including producer-led groups, seed and equipment dealers, as well as agricultural educators, advisors and family.

Agricultural citizen science has promise as a method for generating environmental information from dispersed sites and in an informational context that can support participants in taking action on that information. Specifically, this citizen science effort is providing much needed information about cover cropping as it is practiced in Wisconsin, along with information about how best to support ongoing farmer innovation in rapidly changing agricultural landscapes.

Data availability statement

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

Ethics statement

The studies involving human participants were reviewed and approved by Institutional Review Board—University of Wisconsin–Madison. The patients/participants provided their written informed consent to participate in this study.

Author contributions

MI confirms being the sole author of this manuscript and has approved it for publication.

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Conflict of interest

The author declares 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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