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Perspective of US farmers on collaborative on-farm agronomic research

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Abstract

On-farm research has emerged in recent years as a unique approach to involve farmers and other agricultural stakeholders as active participants in knowledge development and as an effective method of technology and innovation transfer across farms. This study assessed the perspective and knowledge of US farmers regarding on-farm research via the implementation of a 24-question survey distributed across most of the US Midwest and South-Central regions. We found that farmers generally are willing to engage with universities to conduct on-farm research and were 40% more likely to adopt practices supported by on-farm research findings than research not conducted on-farm. Notably, a shift toward conservation practices was made, with cover crops and no-till at the forefront. Insights of this nature have implications for fostering collaborations, addressing constraints, and maximizing the impact of on-farm research, offering guidance for sustainable agriculture progress in the United States and beyond. Results from this research survey could be used to initiate much-needed policies to promote on-farm research. Further, information on the benefits and drawbacks of on-farm research could be used in the development of studies that benefit both farmers and researchers.

1 | INTRODUCTION

On-farm research has emerged in recent years as a unique approach to involve farmers and other agricultural stakeholders as active participants in knowledge development and as an effective method of technology and innovation transfer across farms (Wood et al., 2014). Additionally, farmers worldwide are placing growing emphasis on improving agricultural practices to enhance sustainability and build resilience in the face of various environmental and production challenges (Jayaraman et al., 2021; Pittelkow et al., 2015). Consequently, there is a need for decentralized, inclusive, diverse, and networked approaches to agricultural research, outreach, service, and extension to support farmers in their decision-making processes to achieve their goals (Jackson-Smith & Veisi, 2023). Sackett (2013), Lacoste et al. (2022), Ponzio et al. (2013), and Wood et al. (2014) recommended participatory research with farmer cooperators to develop peer-to-peer networking. Their study indicated that outreach should engage technical assistance providers with locally relevant information. In this scenario, on-farm research can help reduce the risk that research leads toward outputs important to scientists rather than primary users and decision-makers such as farmers (Cook et al., 2013; Lacoste et al., 2022). The shared desire to work together toward a common goal is an important factor in supporting effective learning between farmers and researchers (Hardie Hale et al., 2022). Experimentation on farms can represent a 'multi-win' approach to ensure that researchers focus on relevant topics and that farmers benefit from the knowledge gained from the applied research (Thompson et al., 2019).

On-farm research is broadly defined, according to the Sustainable Agriculture Research and Education (SARE) program, as a study with straightforward experimental design, replications, and statistical analysis conducted as part of a farm using plots large enough to allow the use of farmer's machinery (Chaney, 2017). The motivation for on-farm research is to create a partnership between the researcher and the farmer(s) throughout the project. This innovative process brings agricultural stakeholders together around mutually beneficial experimentation to support farmers' management decisions (Wood et al., 2014). Chaney (2017) and Lacoste et al. (2022) acknowledged that on-farm research is generally supported by three mechanisms that build on the complex and interconnected histories of formal and farmer participatory research: (1) farm fields at meaningful scales (i.e., field scale) under real-world conditions rather than in controlled environment or small experimental plots that are designed in a small part of a field or externally (e.g., industry or university plots); (2) the interests of farmers and/or surrounding community are explicitly acknowledged to allow for building productive relationships; and (3) on-farm research is understood as a process of partnership between researchers and other stakeholders with farmers that pursue shared goals. On-farm research can be initiated through a variety of approaches.

Core Ideas

- Farmers are likely to collaborate with universities to conduct on-farm research.
- Farmers were 40% more likely to adopt practices supported by findings of on-farm research compared to off-farm research.
- The farmers' primary motivators for doing on-farm research were productivity and profitability.
- The farmers' primary source of field information is universities.
- Results from this research survey can drive further policy and initiatives promoting on-farm research.

Thompson et al. (2019) highlighted the three main approaches for on-farm research programs: (1) researcher-initiated; (2) industry-initiated; and (3) farmer-initiated. In the first approach, researchers propose a research topic and recruit farmers to participate. In the second approach, the industry may desire a third-party test of a product or practice, and in the third approach, the research question is generated by a farmer or group of farmers. In reality, most of the on-farm research may be a combination of these approaches and should clearly demonstrate a compelling engagement of farmers in the process.

Despite increasing enthusiasm around the concept of on-farm research within the agricultural community, there are still uncertainties regarding its effectiveness in helping farmers in their day-to-day decisions. Creativity and innovation are always welcome in designing an experiment that will eventually lead to improvements in management decisions and the sustainability of production systems, even if creativity and innovation come with a reasonable level of risk (Krupek et al., 2021). Therefore, the objective of this study was to assess and understand the perspective and knowledge of US farmers regarding on-farm research via the implementation of a survey instrument distributed across most of the US Midwest and South-Central regions. We hypothesized that farmers are eager for partnerships and implementation of on-farm research to facilitate their learning and decision-making and that they consider this an important research and extension service to their operations.

2 | MATERIALS AND METHODS

A qualitative research questionnaire was deployed in the United States (Figure 1) containing three open-ended and 21

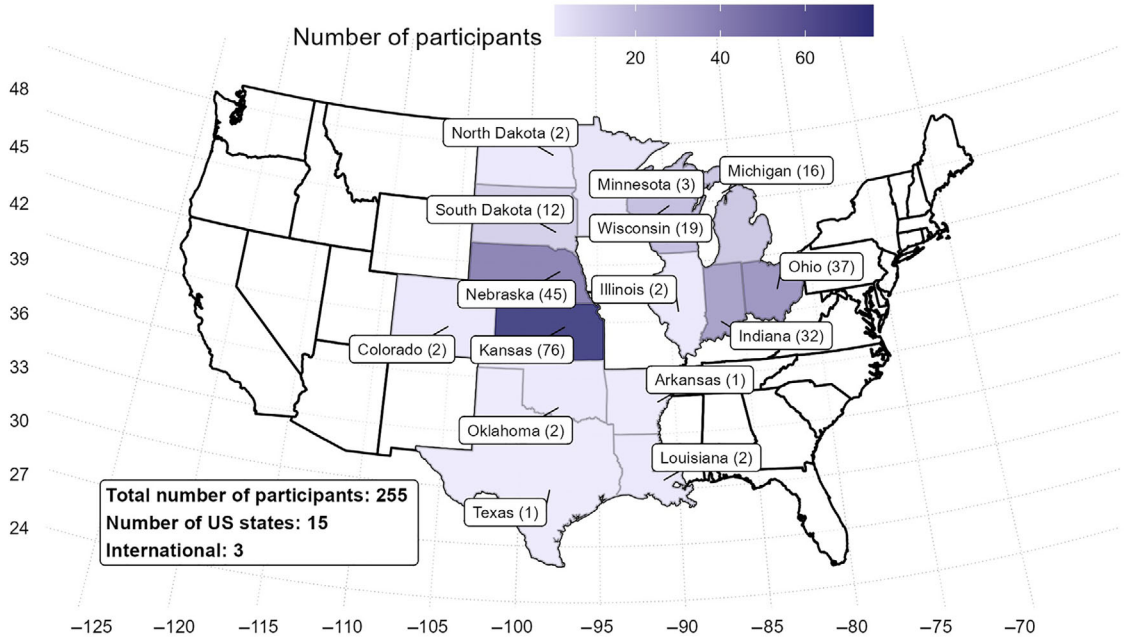

FIGURE 1 Number of participants by US states that completed the on-farm research survey.

closed-ended questions (Table 1) to assess farmers' perception of what on-farm research entails, the importance of and their willingness to participate in on-farm research, and to better understand farmers' farming infrastructure and how it can influence on-farm research capacity. In the case of open-ended questions, participants were instructed to provide written or typed responses, while for closed-ended questions, they were only asked to select from predefined options (Connor Desai & Reimers, 2019).

The questionnaire received approval from the Kansas State University Institutional Review Board to conduct the study (IRB-11084). The farmers were invited to answer the questionnaire during field days (paper or online) and through online links (e.g., social media, listservs, and direct email) shared by researchers and extension agents across the US. from March to July 2022. The survey was deliberately shared to encompass a wide spectrum of farmers without making any distinction based on their preexisting familiarity with on-farm research. This approach was adopted to ensure outreach to a diverse and inclusive farming community. On the approach and invitation, farmers were briefly contextualized on the research objective, promoting entities, and the confidentiality of personal data. Upon agreement of participation, the process of answering the questions was self-instructed, with no influence or assistance from any research and extension staff. The participant could choose not to answer any of the questions. When the questionnaire was answered in paper form, we transcribed the information to the online system to secure the database. The involvement in this survey was completely optional, and participants did not receive any compensation for completing the survey. There were no expected risks or benefits associated with participating.

The questions along with their responses were exported from Qualtrics as a comma-separated value (.csv) text file and manipulated using the R software (R Core Team, 2023). The data were cleaned to remove invalid entries, and figures were built using the ggplot2 (Wickham, 2016) and wordcloud (Fellows, 2018) packages. Absent answers were expressed as NA.

3 | RESULTS

Among respondents, the average age was 50 years, years in production were 25 years, and cropland area was 610 acres (Table 2). The category with the largest number of respondents was 55–64 years old ($n = 65$). Approximately half of the responses were concentrated in the categories at or above 45 years of age, reflecting the current population of farmers managing fields within the United States (USDA NASS, 2019). Regarding years in production, the highest class was between 21 and 40 years ($n = 81$), which represented about 32% of the total responses, whereas 54% of the farmer respondents had at least 21 years in production (Table 2). Among the surveyed population, 96 out of the 255 respondents (38% of the population) farmed more than 1000 acres.

For 79% of the respondents, on-farm research was not a new concept (Figure 2a), suggesting that there is strong familiarity among the farming community in the surveyed population. Of all respondents, 132 had participated in on-farm research and 119 had not (Figure 2b). When asked what best describes

TABLE 1 Questions description, identification number, and number of responses recorded for all 24 questions.

ID	Question	Type	No. of answers
1	What is your age?	Closed	255
2	How long have you been in production?	Open	234
3	What state is your operation located?	Open	252
4	What is the average size, in acres, of cropland in your operation?	Closed	255
5	Is on-farm research a new concept for you?[a]	Closed	251
6	In your opinion, what best describes on-farm research?	Closed[b]	251
7	Have you participated in on-farm research?	Closed	251
8	How likely are you to collaborate with a university (e.g., researchers and extension educators) for conducting on-farm research?	Closed	250
9	How likely are you to adopt practices recommended based on an on-farm study?	Closed	251
10	How likely are you to adopt practices recommended based on a research study other than on-farm study?	Closed	250
11	I consider on-farm research/experimentation an important way to strengthen relationships between producers and a university.	Closed	247
12	In your opinion, what are the top three on-farm research limitations?	Closed[b]	246
13	In your opinion, what are the top three on-farm research strengths?	Closed[b]	247
14	How do you compare on-farm research to other educational opportunities (e.g., greenhouse research and small plots research) available to you?	Closed	239
15	I am satisfied with the investment Universities makes in outreach and extension.	Closed	240
16	How many field days do you attend annually?	Closed	242
17	What type of extension events do you usually attend?	Closed[b]	232
18	On-farm research can foster innovation (use of cover crops, nutrient management, precision agriculture, etc.) to my farm.	Closed	238
19	How often do you consult field information sources?	Closed	235
20	What is your primary source for field information?	Closed[b]	237
21	What has been and/or would be your primary motivator for doing on-farm research?	Closed[b]	239
22	Do you have any major changes to your farming in the last 10 years? Examples: added cover crops, added irrigation, moved to no-tillage, etc.).	Open	174
23	Do you have a yield monitor in your combine?	Closed	234
24	Do you use available precision agriculture technologies?	Closed[b]	233

[a]The definition of on-farm research was shared with the farmers before answering this question.
[b]Close-ended questions with options to choose from and an "other" option.

TABLE 2 Surveyed farmer profiles related to age, years in production, and cropland area expressed in acres.

Age			Years in production			Cropland area (ha)		
Response	*N*	%	Response	*N*	%	Response	*N*	%
<18	6	2.4	<5	17	6.7	<20	23	9.0
18–24	37	14.5	6–10	36	14.1	20–40	18	7.1
25–34	44	17.3	11–20	43	16.9	40–202	70	27.5
35–44	47	18.4	21–40	81	31.8	202–405	48	18.8
45–54	55	21.6	>40	57	22.4	>405	96	37.6
55–64	65	25.5	NA	21	8.2			
>65	6	0.4						
NA	1	2.4						

Abbreviation: NA, not available.

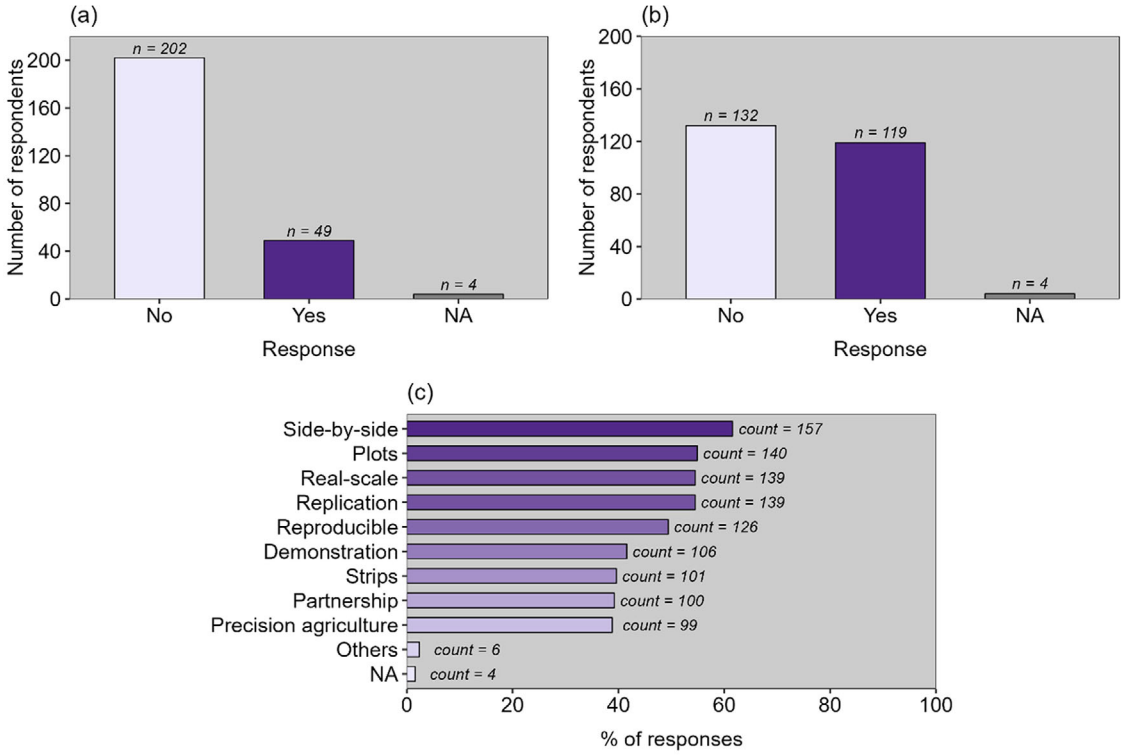

FIGURE 2 Farmers response to: (a) Is on-farm research a new concept for you? (b) Have you participated in on-farm research? (c) In your opinion, what best describes on-farm research?

on-farm research, the most selected answers were *side-by-side* (n = 159), *plots* (n = 140), *real-scale* (n = 139), and *replication* (n = 139) (Figure 2c). *Precision agriculture* and *partnership* had the lowest scores. Among the "others" answer, farmers mentioned "action research that is realistic for farmers to complete," "experimental," "livestock," and "collaboration," representing some of the perceptions that farmers currently have about on-farm research.

The participants were also asked about the likelihood of collaborating with a university to conduct on-farm research (Figure 3a), adopting practices based on findings from an on-farm study (Figure 3b), and adopting practices based on a research study other than an on-farm study. Most respondents were likely to collaborate with universities for conducting on-farm research, demonstrating farmers' readiness for collaboration. Considering the likelihood categories of eight or higher, farmers were 40% more likely to adopt practices based on on-farm studies (66%) compared to other than on-farm studies (26%; Figure 3c). Additionally, farmers were asked about on-farm research as an important way to strengthen relationships between producers and a university. The results showed that 88% of the respondents (n = 224) agreed or strongly agreed that on-farm research was important to strengthen relationships between producers and universities (Figure 3d).

When questioned about their opinion on the limitations (Figure 4a) and strengths (Figure 4b) of on-farm research, time management emerged as the main limitation (n = 195). Another significant limitation was the plot setup. Other limitations mentioned by the respondents were "farmer transferring agronomic data," "year-to-year variability," "data collection," "cost of input for research," "conflict in farmer and university schedule," "funding," "realistic plots that are not in the way of the rest of the operation," "cleaning out drill or planter for each variable," "monetary compensation for time," and "distance to university." Knowledge gained was the main strength (n = 207; Figure 4b) along with access to unbiased research information and applied research. Other strengths of on-farm research mentioned by the respondents were "more localized environments" and "first-hand knowledge of person to contact."

Furthermore, 89.8% of the respondents considered on-farm research above average (n = 128) or one of the best (n = 101) education opportunities when compared to greenhouse or small plot studies (Table 3). Additionally, 85.9% of the respondents agree (n = 127) or strongly agree (n = 92) that on-farm research can foster innovation within their farms; only 6.7% disagree (n = 1) or strongly disagree (n = 16; Table 3).

Upon being asked about their primary motivators for doing on-farm research, farmer responses were productivity and profitability (72.9%, n = 186), getting some questions answered (51.4%, n = 131), environmental stewardship (36.9%, n = 94), receiving recommendations (33.3%, n = 85), and understanding crop functioning (31.4%, n = 80; Table 4).

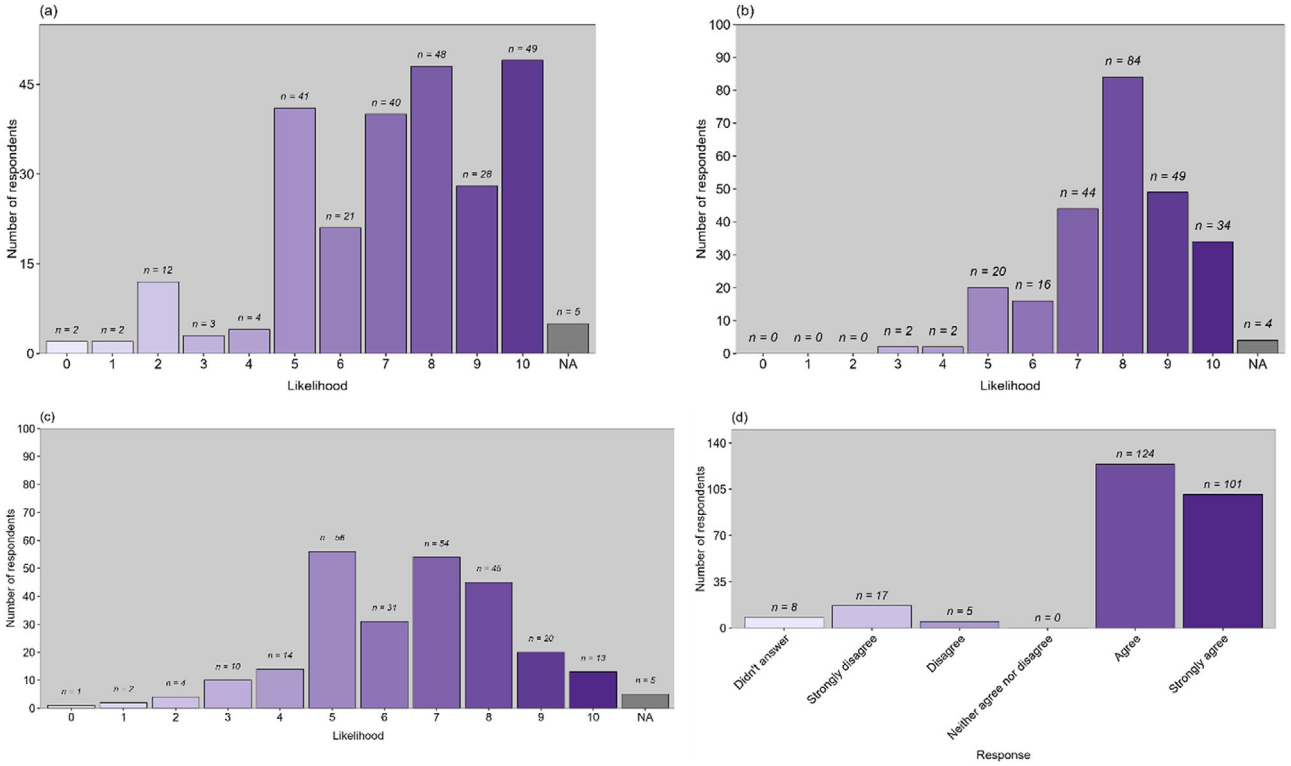

FIGURE 3 Farmers response to: (a) How likely are you to collaborate with a university (e.g., researchers and extension educators) for conducting on-farm research? (b) How likely are you to adopt practices recommended based on an on-farm study? (c) How likely are you to adopt practices recommended based on a research study other than on-farm study? (d) I consider on-farm research/experimentation an important way to strengthen relationships between producers and universities.

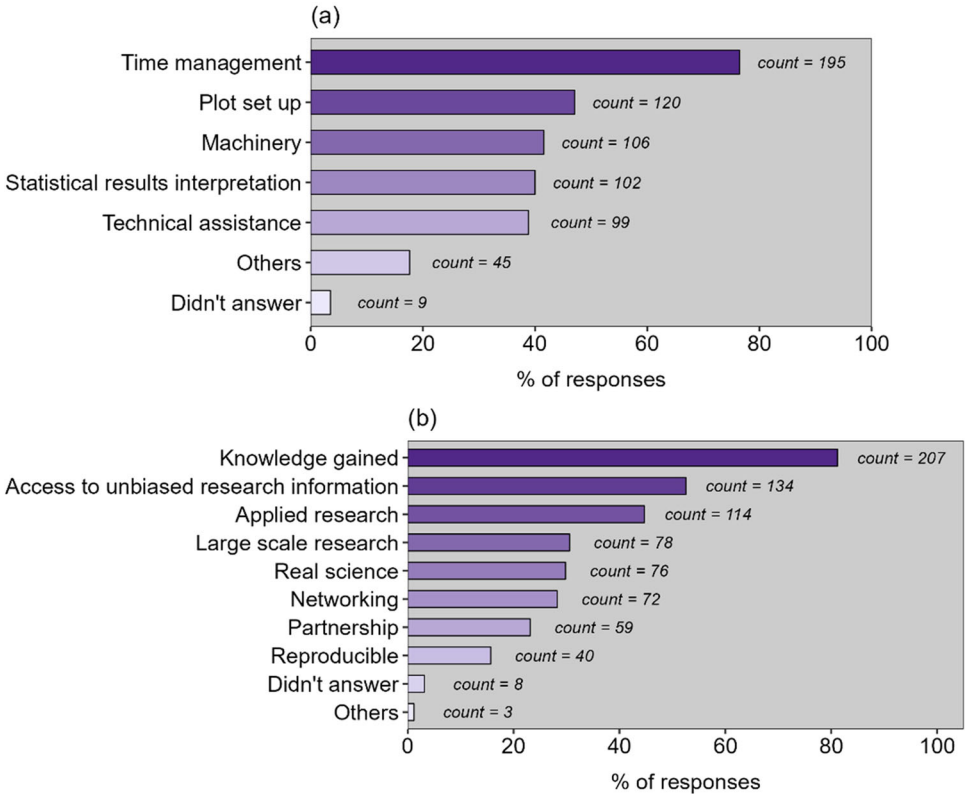

FIGURE 4 Farmers response to: (a) In your opinion, what are the top three on-farm research limitations? (b) In your opinion, what are the top three on-farm research strengths?

TABLE 3 Farmers response to: How do you compare on-farm research to other education opportunities (e.g., greenhouse research and small plots research) available to you? On-farm research can foster innovation (cover crops, nutrient management, precision agriculture, etc.) to my farm.

How do you compare on-farm research to other education opportunities available to you?			On-farm research can foster innovation to my farm.		
Response	***N***	**%**	**Response**	***N***	**%**
Above average	128	50.2	Strongly agree	92	36.1
One of the best	101	39.6	Agree	127	49.8
Below average	10	3.9	Neither agree nor disagree	2	0.8
One of the worst	0	0.0	Disagree	1	0.4
NA	16	6.3	Strongly disagree	16	6.3
			NA	17	6.7

Abbreviation: NA, not available.

TABLE 4 Farmers response to: What has been and/or would be your primary motivator for doing on-farm research?

What has been and/or would be your primary motivator for doing on-farm research?		
Response	***N***	**%**[a]
Productivity and profitability	186	72.9
Enabling digital agriculture	19	7.5
Food security	23	9.0
Networking and sharing	74	29.0
Environmental stewardship	94	36.9
Get some questions answered	131	51.4
Receive recommendations	85	33.3
Understand crop functioning	80	31.4
Others	15	5.9
NA	16	6.3

Abbreviation: NA, not available.

[a]Percentage of multiple-choice questions is related to each possible answer.

Enabling digital agriculture (7.5%, $n = 19$) and food security (9%, $n = 23$) were not primary motivators. Among the other options, farmers mentioned "to advance soil health research," "help university with research," "seeing new things being tried without taking financial risks," "reducing need of inputs," "to improve soil health and water quality," "manage climate change," "maintain extension relations," and "support to learn and understand."

Once queried about their satisfaction with the university's investment in outreach and extension, 13.3% responded that they strongly agree that they are satisfied, 42% agree, 9.4% neither agree nor disagree, 5.9% disagree, and 23.5% strongly disagree (Table 5). Undoubtedly, the most extension events attended by the respondents were field days (65.5%, $n = 167$), followed by meetings (45.1%, $n = 115$), conferences (40.4%, $n = 103$), and workshops (43.5%, $n = 111$; Table 5). The majority of the respondents (59.2%) attend 1 ($n = 68$) or 2 ($n = 83$) field days per year, and 12.5% do not attend any field day (Table 5). Other types of events referenced by the respondents were "ranch tours," "webinars," "reading online," and "Zoom calls."

According to farmer responses, their main sources of field information were universities ($n = 164$) and private industry ($n = 145$), with public institutions like the USDA ranking third ($n = 81$) in the list (Figure 5a). Other sources of information given by the participants were "other producers," "seed companies," "growers associations," "crop consultants," "magazines," "private groups," "newsletters," "industry trade groups," and "books." Most of the respondents consult information sources less than once a month ($n = 66$), once a month ($n = 71$), and once a week ($n = 63$; Figure 5b).

To understand what is new regarding management practices, the farmers were questioned about the major changes in their farming in the last 10 years (Figure 6). Out of the 255 farmers, 41.6% ($n = 106$) of them cited cover crops and 17.6% ($n = 45$) no-till as major changes to their farming, followed by irrigation (5.5%, $n = 14$), precision agriculture (5.5%, $n = 14$), diverse crop rotation (4.3%, $n = 11$), and reduced tillage (3.9%, $n = 10$). Ninety farmers reported no changes (35.2%). Understanding that precision agriculture is one of the main new approaches to agriculture, farmers were asked whether they use available precision agriculture technologies (Figure S1); 54 responded that they do not use precision agriculture technologies; 131 use grid soil sampling; 124 use variable rate fertilizer; and 94 use variable rate seeding. Since combine-mounted yield monitors are one of the proctors for implementing on-farm research, the farmers were asked whether they have it available; 171 farmers have yield monitors available (Figure S2).

4 | DISCUSSION

This study provides unique evidence on the overall perspective of US farmers regarding on-farm research. Although our

TABLE 5 Farmers response to: I am satisfied with the investment universities make in outreach and extension. What type of extension events do you usually attend? How many field days to you attend annually?

I am satisfied with the investment universities make in outreach and extension.			What type of extension events do you usually attend?			How many field days do you attend annually?		
Response	***N***	**%**	**Response**	***N***	**%[a]**	**Response**	***N***	**%**
Strongly agree	34	13.3	Field days	167	65.5	None	32	12.5
Agree	107	42.0	Workshops	111	43.5	One	68	26.7
Neither agree nor disagree	24	9.4	Seminars	90	35.3	Two	83	32.5
Disagree	15	5.9	Meetings	115	45.1	Three	19	7.5
Strongly disagree	60	23.5	Summits	19	7.5	>4	40	15.7
NA	15	5.9	Conferences	103	40.4	NA	13	5.1
			Others	23	9.0			
			NA	23	9.0			

Abbreviation: NA, not available.

[a]Percentage of multiple-choice questions is related to each possible answer.

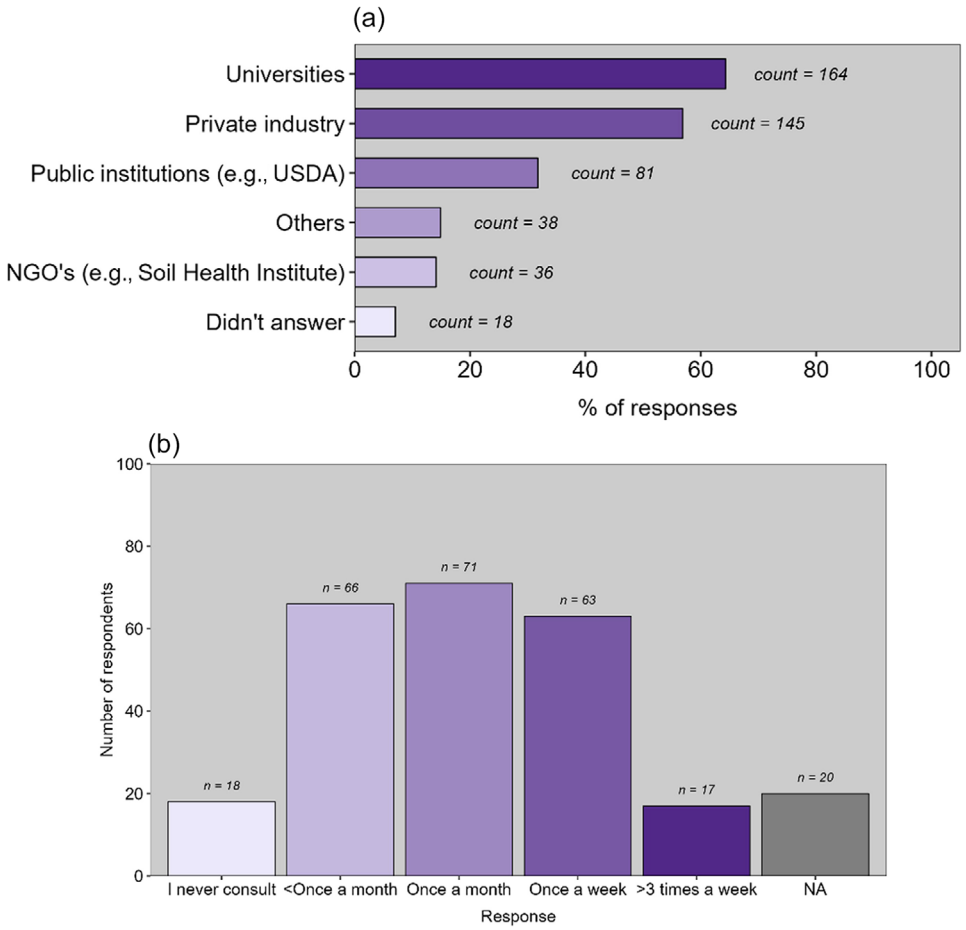

FIGURE 5 Farmers response to: (a) What is your primary source for field information? (b) How often do you consult field information sources?

sample size was relatively small compared to the total number of farmers in the United States, the survey effectively covered a large geographical area. It revealed that on-farm research is a relevant topic for many US farmers. The average age of the survey respondents was 50, which falls close to the average age of farm producers (57) reported in the 2017 Census of Agriculture (USDA NASS, 2019). Approximately 34% of the respondents were less than 35 years old ($n = 87$),

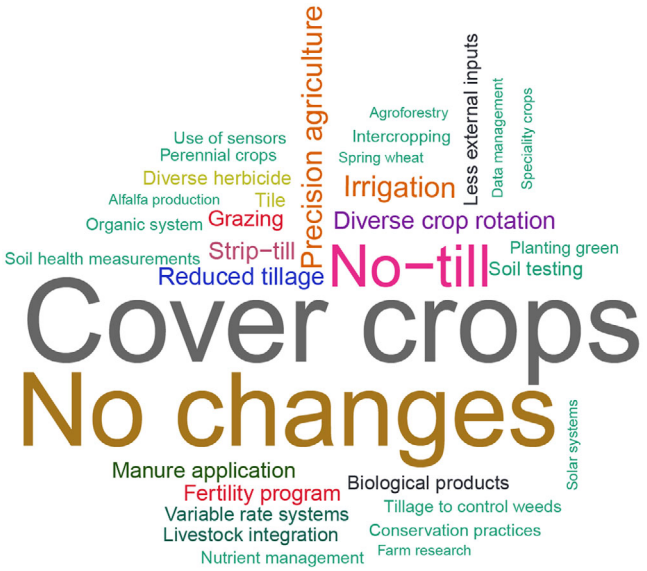

FIGURE 6 Farmers response to: Did you have any major changes to your farming in the last 10 years? Minimum and maximum frequencies were expressed as: 1, 106.

representing a younger generation of farmers. Young farmers may act as bridges linking distinct groups of farmers and help disseminate critical information, such as adopting new practices or adapting to new challenges (Parks, 2022). The average cropland area from the survey (610 acres) approximates the average US farm size reported by the USDA (446 acres) (USDA NASS, 2023). The data presented in Figure 5a suggest that on-farm research is not a new or unfamiliar concept for most of the surveyed population. This finding aligns with Kyveryga (2019), who stated that on-farm research rapidly expanded during the last two decades, especially in developed countries like the United States. For instance, the Nebraska on-farm research network completed 101 on-farm studies from 1990 to 2019. One of the main reasons for this increase was the use of precision agriculture tools such as global navigation systems, variable rate devices, and yield monitoring (Bullock et al., 2019; Kyveryga, 2019). Precision agriculture was considered by 99 farmers as one of the best describers for on-farm research. Although most of the surveyed farmers were familiar with on-farm research, they had a split level of involvement. One of the explanations for the varying degree of engagement was that participatory research applies more to resourceful farmers than to marginal ones (Witcombe, 1999). On-farm research is often, but not only, adopted by farmers that use modern technology and can overcome labor and time management challenges with geographic information system (GIS) and precision agriculture systems. These farmers may use global navigation satellite systems-driven equipment for plot establishment, planting, and harvesting (Bullock et al., 2019). Similarly, variable rate systems and sprayers with section control may be used and help to overcome time management, the main on-farm research limitation highlighted in this study. It is also important to consider that although modern technology can certainly help the on-farm research process regarding time and labor management, farmers deciding whether to engage in on-farm research may go beyond the availability of precision agriculture systems and farm machinery. Also, systems-thinkers and risk-taking farmers might be more willing to conduct on-farm research and adopt new practices (Church et al., 2020).

The terms that best described on-farm research included side-by-side, plots, real-scale, and replication, indicating that the respondents associate on-farm research with practices that involve comparing different treatments or interventions under actual farming conditions and observing their effects in a replicated manner. This finding underscores the importance of conducting research on actual farms to achieve scalable results and perhaps the adoption of certain practices (Lacoste et al., 2022). The concept of partnership, which signifies a connection between farmers and research institutions such as universities, received one of the lowest scores among the respondents. This suggests that the current perceived level of collaboration between farmers and research institutions might be relatively low, or farmers do not believe they need partnerships for conducting on-farm research. Despite this result, the respondents also valued on-farm research as a way to build connections with researchers and extensionists. It would be imperative for researchers trying to establish on-farm research to articulate and develop the partnership concept better. Thompson et al. (2019) underlined that positive experiences in the Nebraska on-farm research program were primarily credited to interactions between the university and farmers. Even though the data suggest that the current level of collaboration is relatively low, the survey data indicate that most respondents expressed a positive inclination toward collaboration with universities for on-farm research. This suggests that although some farmers may be skeptical, most tend to be open to partnering with universities to conduct research activities on their farms. This willingness for collaboration highlights the potential for productive interactions between farmers and researchers (Adamsone-Fiskovica & Grivins, 2022; Toffolini & Jeuffroy, 2022). Further exploration of this aspect could provide value for improvement in fostering more robust partnerships between farmers and research institutions in the United States while serving as a model example for other regions across the globe.

Our data revealed that a substantial percentage of respondents indicated a high likelihood of adopting practices recommended based on on-farm studies. This shows a high level of trust and confidence among farmers in the findings and recommendations derived from on-farm research. In Nebraska, 75% of farmers interviewed by Thompson et al. (2019) had put their research results into practice in their farm operations, either by making a change based on on-farm research

results or by not making a change as the research confirmed better results using their current practices. It is important to note that farmers recognize the relevance and applicability of on-farm studies and their willingness to implement the practices suggested by such research to improve their farming operations. In the study by Thompson et al. (2019), a farmer who was interviewed mentioned having intentions of making a change. However, the research outcomes ultimately provided the necessary confidence to carry out the proposed practice. Our own findings, consistent with other research, suggest that researchers should deepen their understanding, educate students, and actively work toward expanding networks for on-farm research. By doing so, the adoption of new practices can be accelerated and enhanced. The notably higher likelihood of adoption observed through participation in on-farm research is a robust indicator of its potential impact. This, in turn, should play a crucial role in shaping decisions made by both university administrations and government policymakers. Additionally, it may assist in promoting more targeted outreach and extension efforts.

Furthermore, the adoption rate of practices not tested with on-farm research (e.g., small plots and greenhouses) is significantly lower, and only 25% of the recommended practices from non-on-farm studies are likely to be adopted by farmers. This disparity highlights the perceived value and credibility that farmers place on on-farm research compared to other types of research. It also underscores the importance of conducting research directly on farms to generate recommendations that farmers find more relevant and applicable to their specific contexts and environments (Koehler-Cole et al., 2023; Snapp et al., 2023). On-farm research, hence, has the potential to become a leading catalyst for helping farmers to adopt sustainable practices. Nevertheless, the importance of small plots and greenhouse studies cannot be understated in the context of agricultural development. Such efforts are crucial in refining the list of potential practices that can realistically be subjected to on-farm comparisons. Another outcome of this work is that 88% of the farmers who agreed or strongly agreed that on-farm research is important for strengthening relationships between producers and universities serve as an indication that farmers recognize the potential benefits of on-farm research beyond the specific research outcomes. Previous research has indicated that farmers value the collaborative aspect of on-farm research and acknowledge its role in fostering stronger connections and partnerships between themselves and research institutions (Snapp et al., 2023). The mutual understanding of the importance of on-farm research for relationship building further emphasizes the potential for fruitful collaborations between farmers and universities across the United States.

When considering the limitations of on-farm research, the respondents identified time management as the main challenge. Allocation of time is a significant constraint when engaging in on-farm research activities. Another noteworthy limitation mentioned by the respondents was the plot setup, which implies that establishing and maintaining research plots on farms can pose practical challenges. On the other hand, the respondents recognized several strengths of on-farm research. The most prominent strength mentioned was the knowledge gained from conducting research on their farms. This finding highlights the value of on-farm research in generating practical knowledge and insights directly applicable to farmers' operations. Access to unbiased research information and the opportunity to conduct applied research were also emphasized as strengths of on-farm research. In-depth interviews with farmers from the Nebraska On-Farm Research Network revealed that farmers conducted on-farm research mainly to increase profitability and to fulfill their need for unbiased results (Thompson et al., 2019). Moreover, the farmers responded that they consider on-farm research one of the best education opportunities, demonstrating its educational value and effectiveness as a learning-by-doing opportunity for farmers (Krupek et al., 2021; Snapp et al., 2023). This also indicates a positive attitude toward the impact of on-farm research in driving and supporting farm-level innovation.

On-farm research is demand-driven (Lacoste et al., 2022). Unsurprisingly, the primary motivator for doing on-farm research was productivity and profitability ($n = 186$), which underscores the practical and economic considerations that drive farmers to conduct research on their farms. Farmers recognize that implementing research-based practices can increase productivity and profitability, making it a crucial motivation for their involvement in on-farm research activities. Another significant motivator identified by 131 farmers was the desire to get some questions answered, which is most often a shared goal between farmers and researchers. This suggests farmers engage in on-farm research to address specific questions or uncertainties about their farming practices, which can align well with entities assisting in the research process (e.g., educators, universities). Another important motivator was environmental stewardship. This motivator can be directly linked to the major changes that the respondents had on their farms. Unquestionably, the recent adoption of cover crops and no-tillage (Figure 6) pointed farmers toward increased agricultural sustainability, resilience, and environmental stewardship. In the "other" category, farmers also cited that "advancing soil health research," "reducing the need for inputs," "improving soil health and water quality," and "managing climate change" are important motivators. The survey did not identify enabling digital agriculture and food security as primary motivators. While these aspects are important (Bullock et al., 2019), they may not be the primary driving forces behind farmers' engagement in on-farm research activities across our surveyed population.

Field days were the most popular events attended by farmers, followed by meetings, conferences, and workshops. This

reveals that farmers actively engage in these face-to-face events to acquire knowledge and stay updated with the latest information available to manage their fields (Heiniger et al., 2002). It is worth noting that a surprising number of respondents, 32 in total, reported not attending any field day, indicating a potential gap in their access to this type of extension activity. Field days are an important opportunity to facilitate the adoption of desired farming practices and have been a staple of agricultural organizations for a long time (Singh et al., 2018). However, highlight the changes and alternatives for knowledge delivery used by a certain group of farmers, and the extension delivery approach should constantly explore alternative methods.

Both universities and private industry serve an important role as sources of field information for farmers and were cited as the most influential by the farmers, followed by public institutions like the USDA. This result brings the opportunity to trusted organizations such as Land Grant Universities to foster networking opportunities between well- and less-connected farmers to guide new trusting relationships of knowledge exchange. The adoption of practices by farmers can be increased when using a knowledge network supported by programs and resources that incorporate technical, social, and experiential learning pathways (Wick et al., 2019). Respondents also mentioned other valuable sources, such as other producers, seed companies, and grower associations. Friendly communication with neighbors or trusted partners tends to be more readily trusted than information from outsider sources (Hoffmann et al., 2007). In the United Kingdom, farmers were more willing to try a new sustainable agricultural practice when influenced by another farmer or an advisor they knew, trusted, and had a long-term relationship (Rust et al., 2021). This highlights the importance of establishing trust via on-farm research networks to involve the farming community and tackle critical concerns related to production, profitability, and the environment. Farmers are usually more open to new practices when they learn them through observation, trials, and two-way dialogue (Tarnoczi & Berkes, 2010). Importantly, our study revealed that farmers rely on diverse sources to gather information and knowledge about their farming practices and are regularly interested in accessing new knowledge and staying informed about management practices, just as suggested by Rust et al. (2022). The frequency (e.g., once a month or better) at which farmers use field information is a robust opportunity for researchers and universities to influence and support the decision-making process by farmers. Although most respondents are satisfied with university investment in research and extension, the data indicated some level of dissatisfaction among some farmers. Augmented investment could potentially become imperative to align with farmers' expectations and requirements, as well as to facilitate the nationwide utilization of on-farm research to enhance adoption rates.

Regarding major changes in their farming practices in the last 10 years, cover crops and no-till dominated the responses. This reflects a significant shift toward conservation-oriented practices to improve soil health and reduce environmental impacts (Bonini Pires et al., 2020; Bowman et al., 2022). Other changes mentioned included irrigation, precision agriculture, diverse crop rotations, and reduced tillage. Our results may reflect the current research agenda and investments that conservation agriculture (e.g., cover crops, no-till) research has received in recent years. Increased funding and resources have become available in recent years for agricultural producers to improve soil health and prevent nutrient loss and erosion (Popovici et al., 2023). Notably, 35% (n = 90) of the farmers reported no changes, indicating a potential resistance or slower adoption of new practices. Alternatively, it may represent that some producers have already incorporated these practices into their regular operation for more than 10 years. For late adopters, mentoring from a trusted source could be critical to facilitate the adoption of new practices (Bagnall et al., 2020). In terms of precision agriculture, our study suggests that while some farmers are adopting new agriculture technologies, a portion of the farming community still has not embraced these advanced tools. McFadden et al. (2023) surveyed US farmers to understand the adoption of precision agriculture in the digital area. The authors reported that in many cases, the adoption decisions were based on their expectation of how the tools would affect their farming operation's performance. In addition, the availability of combine-mounted yield monitors throughout the survey community was high. Thus, a considerable number of farmers have the necessary tools for collecting yield data, which can contribute toward implementing on-farm research (Gauci, 2022) and address productivity and profitability concerns. These were primary motivators for farmers to engage in participatory on-farm research.

Overall, this study features farmers' high trust in on-farm research outcomes, influencing practice adoption. Limitations like time management and plot setup were identified, while strengths included practical knowledge gained and unbiased insights. Notably, a shift toward conservation practices was evident, with cover crops and no-till at the forefront. Insights of this nature have implications for fostering collaborations, addressing constraints, and maximizing the impact of on-farm research, offering guidance for sustainable agricultural progress in the United States and potentially beyond.

AUTHOR CONTRIBUTIONS

Carlos B. Pires: Conceptualization; data curation; formal analysis; investigation; visualization; writing—original draft. **Fernanda S. Krupek**: Conceptualization; investigation; writing—original draft. **Gabriela I. Carmona**: Conceptualization; investigation; writing—original draft. **Osler A. Ortez**: Conceptualization; investigation; writing—original

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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