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Assessment of cover crop adoption and impact on weed management in Wisconsin corn-soybean cropping systems

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Abstract

The evolution and widespread occurrence of herbicide-resistant weeds pose a major challenge for farmers and crop consultants across North America, warranting integrated management strategies. The adoption of cover crops offer weed suppression and soil health benefits but adds management complexity. A survey, targeting farmers and crop consultants, was conducted during the spring of 2023 to evaluate current cover crop management practices and perceptions in Wisconsin cropping systems. The survey included 26 questions across five sections: respondent profile, cover crop adoption and experience, cover crop management ahead of soybean [*Glycine max* (L.) Merr.], cover crop management ahead of corn (*Zea mays* L.), and general benefits and challenges of cover crop adoption. Farmers and crop consultants represented most respondents, influencing a total of 29,500 and 557,000 ha, respectively. Waterhemp (*Amaranthus tuberculatus* [Moq.] J.D. Sauer) and giant ragweed (*Ambrosia trifida* L.) were identified as the most troublesome weeds. Over 90% of respondents use herbicides to terminate their cover crops, and 68% of respondents agree that cover crops improved overall weed control in their farms/clients' farms to some extent [cereal rye (*Secale cereale* L.) as main cover crop species]. Additionally, results demonstrate a strong consensus (85%) on cover crops positively influencing water retention, with 98% agreement on their efficacy in reducing soil erosion. Results from this survey can help guide farmers, agronomists, researchers, and policymakers with cover crop adoption, management, policies, incentives, and future research and education needs in Wisconsin and beyond to support the development of more sustainable and efficient weed and crop management strategies.

1 | INTRODUCTION

The increasing prevalence of herbicide-resistant weeds is a significant concern for farmers and crop consultants (Peterson et al., 2018). Despite herbicides remaining as the primary tool for weed control, an integrated approach to weed management is warranted (Kniss, 2018: Norsworthy et al., 2012). Integrated weed management comprises an approach that combines various methods, such as cultural, mechanical, biological, and/or chemical weed control, with the end goal of

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achieving a more robust and long-term weed management system (Swanton & Weise, 1991), providing the crops with an advantage over weeds (Harker & O'Donovan, 2013).

The adoption of soil conservation practices, such as no-till and cover crops, offer soil health benefits as an alternative to traditional tillage systems (Blanco-Canqui & Lal, 2009). In the upper US Midwest, growers predominantly adopt cereal rye (*Secale cereale* L.) as a cover crop due to its capacity to thrive within the region's constrained growing season, between cash crop harvest and planting, and its resilience against severe winter conditions (Clark, 2007). Cereal rye starts its growth cycle in the fall and resumes growth in spring, providing soil coverage in the spring until termination time, whereas postponing termination can typically increase cover crop biomass, extending soil protection beyond cash crop planting time (Kaspar & Bakker, 2015). Conversely, if terminated too early, rapid decomposition can occur, potentially failing to effectively protect the soil in the spring (Mirsky et al., 2013). Cereal rye cover crop can serve as an additional tool for early season weed suppression (Grint, Arneson, Oliveira, et al., 2022), enhancing sustainability in weed management programs, and reducing herbicide resistance selection pressure (Werle et al., 2017). Additionally, no-till systems without cover crops rely more heavily on herbicides compared to tillage and cover crop systems, as more weeds need to be chemically controlled at crop planting time (i.e., burndown; Bunchek et al., 2020; Davis, 2010).

Agricultural stakeholder surveys serve as invaluable tools for documenting perceptions, management strategies, and research needs that influence agronomic decisions (Givens et al., 2009). The objective of this survey was to gather insights and perspectives from agricultural stakeholders on their current practices, challenges, and concerns regarding cover crop adoption in corn-soybean rotations within the state of Wisconsin and their weed management implications.

Core Ideas

- Herbicide-resistant weeds are of significant concern, requiring integrated management approaches.
- Agricultural stakeholder surveys are essential for understanding current practices and guiding future research.
- Waterhemp and giant ragweed are identified as the most troublesome weed species in Wisconsin.
- Cereal rye is the preferred cover crop for its winter resilience and high biomass accumulation in the spring.
- Most respondents (68%) perceived cover crops as improving overall weed control in their operations.

2 | MATERIALS AND METHODS

The survey targeted farmers and crop consultants aiming to assess and document how cover crops are currently being adopted, managed, and perceived as part of crop and weed management programs in Wisconsin cropping systems, with a focus on soybean and corn production. The survey was made available online using Qualtrics survey platform (Qualtrics), from February to April of 2023. A link to the survey was distributed via email to the Wisconsin Cropping Systems Weed Science lab listserv (wiscweeds-update@g-groups.wisc.edu, 850 members), Twitter, and a QR code leading to the survey was presented during winter extension meetings presentations.

The survey consisted of 26 questions divided into five sections. The first section consisted of respondent profile details such as occupation, farm size, and crops managed. The second section focused on cover crop adoption and experience. The third section determined details on cover crop management ahead of the soybean season. The fourth section determined details on cover crop management ahead of the corn season. The final section included general questions regarding the benefits and challenges of cover crop adoption. In the survey, only one response was allowed for questions Q1, Q3, Q7, Q8, Q10, Q11, Q14, Q15, Q16, and Q17, so the cumulative total for these questions add up to 100%. Questions Q4, Q5, Q6, Q12, and Q13 allowed for multiple responses, leading to cumulative totals exceeding 100%.

Data collected from the survey were exported as a Microsoft Excel (Microsoft Corporation) file with the answers to each question in separate columns. Data were summarized, analyzed, and plotted using R statistical software version 4.3.1 (R Core Team, 2023). The packages "dplyr" and "tidyr" were used for data manipulation, "ggplot2" for data visualization, and base R functions were used for statistical analyses.

For ranking questions (Questions 9 and 18), respondents were instructed to drag management strategies according to their perception of importance, with one representing the most important and the highest number representing the least important (e.g., six was the least important in a ranking question containing six management strategies). To rank important management strategies related to establishing cover crops and the challenges of incorporating them, a relative importance point system was employed (Sarangi & Jhala, 2018). Points were assigned to each management strategy according to its ranking. In a question with six options, rank #1 received six points, rank #2 received five points, and so forth, until rank #6, which received one point. The relative importance point (RP) for each option was determined using the following equation

(Sarangi & Jhala, 2018):

$$\mathrm{RP} = \sum_{r=1}^{6} \frac{FX}{n}, \quad (1)$$

where F represents the number of respondents selecting a specific rank (r) for a management strategy, X indicates the importance points associated with that rank, and n is the total number of responses for that rank, considering all available management strategies.

To evaluate the relationship between the occupation of respondents and their responses to whether cover crops improved weed control, responses were filtered to include only "farmers" and "crop consultants" as the two main categories. A contingency table was created and used to assess whether the distribution of responses differed by occupation through chi-square test of independence (McHugh, 2013; Sharpe, 2015). To facilitate interpretation and simplify analysis when evaluating response relationship between occupations, the perception on cover crops' impact on weed control was reclassified by grouping similar categories (e.g., combining "strongly agree" with "somewhat agree" into "agree").

3 | RESULTS AND DISCUSSION

3.1 | Respondent profile

The survey had a total of 136 respondents, including 59 crop consultants, 63 farmers, six conservation agency representatives, one researcher, and seven identified as "other" (e.g., ag retailer, part-time farmer, extension educator). More than 89% of respondents were composed of farmers and crop consultants (Q1, Table 1). The majority of respondents farm/consult in the South Central or West Central Region of Wisconsin, with 55 out of the 72 state counties represented in the survey (Figure 1).

The average area covered for the respondents that identified as farmers is 469 ha (median = 223 ha), while for crop consultants it is 9447 ha (median = 4049 ha). The total area covered by respondents, including both farmers and crop consultants, in the survey is 586,900 ha. For comparative analysis, in 2023 in Wisconsin, 1.61 million ha were planted with corn (1.27 million ha for grain) and 854,000 ha with soybean (USDA-NASS, 2024).

The survey was targeted at corn–soybean farmers/consultants, with the two crops being reported by the majority (93%) of respondents (Q4, Table 1). It is important to note that other crops such as wheat, alfalfa, and pasture can be part of the rotation for these growers and the variety of clients that consultants advise.

The most troublesome weed species reported by respondents are waterhemp, giant ragweed, and foxtail species (green, yellow, and giant foxtail) being reported by 80%, 67%, and 39% of the respondents, respectively (Q5, Table 1; Figure 2). Giant ragweed and waterhemp have been consistently identified as significant issues over the past couple of years (2018–2024) in Wisconsin (Arsenijevic et al., 2022; Werle et al., 2023), while Ficket et al. (2013a, 2013b), conducting a survey in corn and soybean fields across Southern and Northeastern Wisconsin during 2008 and 2009, identified grasses and sedges as the most abundant weeds early in the season, followed by common lambsquarters and velvetleaf.

3.2 | Cover crop adoption

The most used cover crop species was cereal rye, being reported by the majority (96%) of the respondents, followed by legumes, such as clover, pea, and vetch (Q6, Table 2). Cereal rye is the predominant cover crop species adopted by growers in the upper Midwest due to its ability to thrive in the region's limited growing season between cash crop harvest and planting and severe winter (Clark, 2007).

When asked about the years of experience with cover crops, 60% of the respondents indicated to have between 3 and 10 years of experience, while 18% have <3 years, and 22% have >10 years of experience with cover crops (Q7, Table 2). Moreover, 50% of the respondents indicated the adoption of cover crop in 20% or less of their total acreage, while 10% of respondents have >80% of their acreage being cover cropped (Q8, Table 2). The adoption of cover crops in a small percentage of the acreage highlights possible barriers to cover crop adoption. Even though most respondents have some experience with cover crop, barriers such as economic constraints, perceived risks, and operational challenges persist.

Respondents ranked soil erosion reduction as the top priority when establishing cover crops, followed by soil health improvement, weed management, and water infiltration (Q9, Table 2).

Cover crops are effective in preserving soil integrity by reducing wind and water erosion (Chalise et al., 2019). Moreover, 68% of the respondents agreed that cover crops improved overall weed control in their farm/client's farm to some extent (Q10, Table 2). Moreover, responses were reclassified by combining "strongly agree" and "somewhat agree" into "agree," and "strongly disagree" and "somewhat disagree" into "disagree," while retaining "neither agree nor disagree" as "neutral." The analysis revealed that 37 crop consultants and 39 farmers agreed with the statement, six crop consultants and eight farmers disagreed, and seven crop consultants and 12 farmers remained neutral. Thus, 66% of farmers and

TABLE 1 Section 1: Respondent profile (observations [n] = 136).

Q1: How do you categorize yourself? (main occupation)		
	Occupation	%
	Conservation agency	4
	Crop consultant	43
	Farmer	46
	Researcher	1
	Other	6
Q2: Which Wisconsin county(ies) do you farm/consult/work?		
Open ended	**Figure 1**	
Q3: How many acres did you farm/consult/work in the 2022 cropping season?		
Open ended	**Area intervals**	%
	0–100	21
	100–250	13
	250–500	10
	500–1000	7
	1000–5000	26
	5000–10,000	13
	10,000–100,000	8
	100,000<	2
Q4: What crops did you grow/consult for the past 5 years?		
	Crop	%
	Corn	93
	Soybean	93
	Wheat	70
	Alfalfa	69
	Pasture	49
	Other[a]	27
Q5: What are the most troublesome weeds where you farm/consult?		
Weed species		%
Common lambsquarters	*Chenopodium album* L.	29
Common ragweed	*Ambrosia artemisiifolia* L.	21
Fall panicum	*Panicum dichotomiflorum*	28
Foxtail species	*Setaria* spp.	39
Giant ragweed	*Ambrosia trifida*	68
Horseweed	*Erigeron canadensis*	25
Other species[b]	-	18
Redroot pigweed	*Amaranthus retroflexus*	15
Velvetleaf	*Abutilon theophrasti*	26
Waterhemp	*Amaranthus tuberculatus*	81
Woolly cupgrass	*Eriochloa villosa*	8

[a]Barley (*Hordeum vulgare* L.), oat (*Avena sativa* L.), pea (*Pisum sativum* L.), green bean (*Phaseolus vulgaris* L.), sorghum (*Sorghum bicolor* L.), and potato (*Solanum tuberosum* L.).

[b]Barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.], wild proso millet (*Panicum miliaceum* L.), and dandelion (*Taraxacum officinale* F. H. Wigg.)

74% of crop consultants agreed with this statement, and the chi-square test of independence analysis indicates no significant association between respondents' occupation and their response to the question (p-value = 0.632).

Effective weed suppression relies significantly on the selection of cover crop species (McKenzie-Gopsill et al., 2022), with those establishing quickly and producing substantial biomass showing higher potential for weed suppression (Dorn

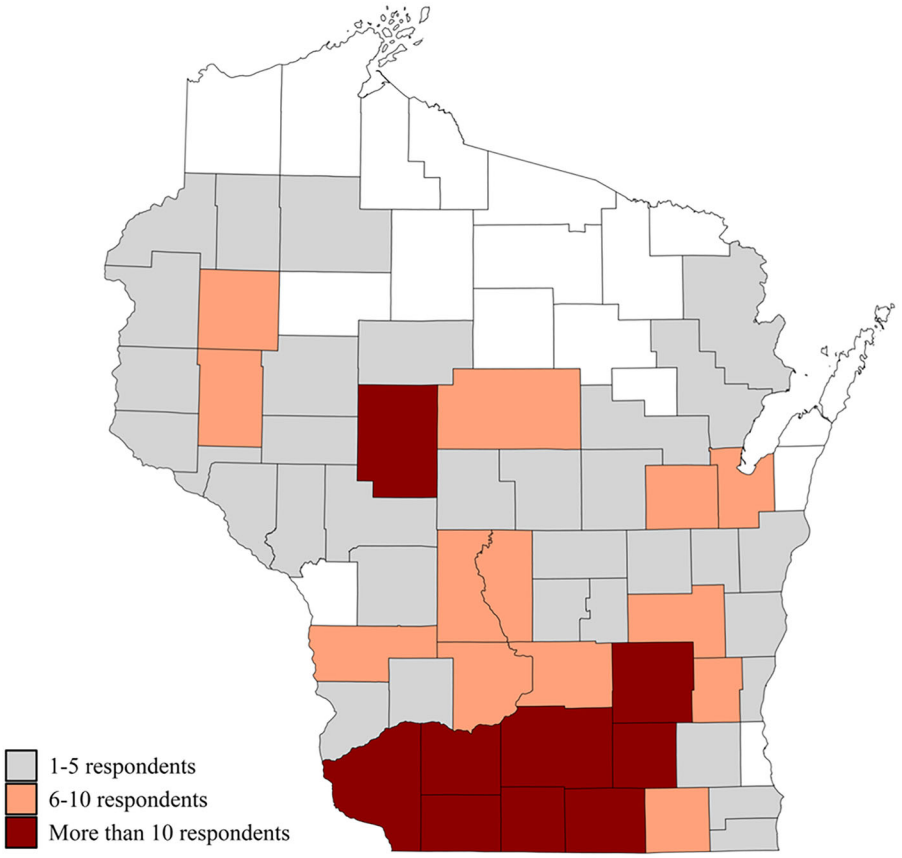


FIGURE 1 County map of Wisconsin. Colors represent the number of answers obtained per county.

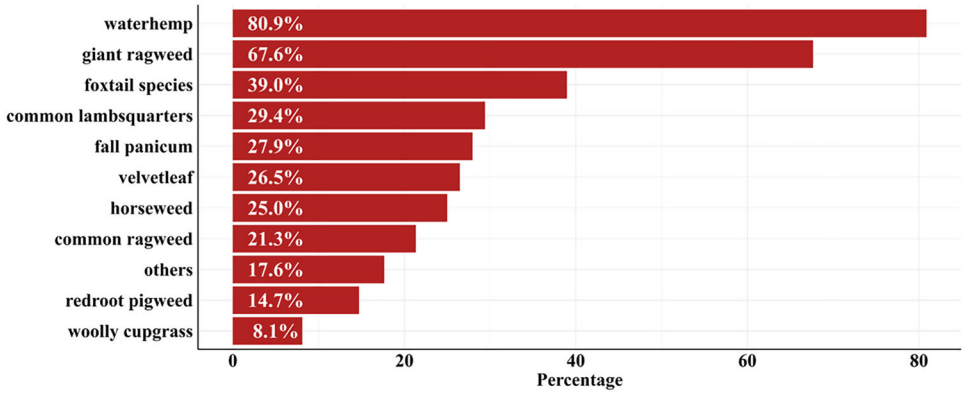


FIGURE 2 Respondents' answer to "What are the most troublesome weeds where you farm/consult' (Question 5). Respondents were able to select all that apply.

et al., 2015). The higher adoption of cereal rye pointed by respondents (Q6, Table 2) is beneficial from a weed management perspective, given the higher biomass production of this species (Kaspar & Bakker, 2015) compared to the other cover crop options in this survey, supported by research conducted in Wisconsin where cover crops improved weed management (Chudzik et al., 2023; Grint, Arneson, Oliveira, et al., 2022; Nunes, Arneson, Wallace, et al., 2023).

3.3 | Cover crop management ahead of cash crop

Respondents indicated various termination times for cover crops preceding soybean planting, with 27% terminating between planting and 7 days after planting, followed by 26% terminating between 7 and 14 days before planting (Q11, Table 3). Given the widespread adoption of cereal rye as a

TABLE 2 Section 2: Cover crop adoption (observations [*n*] = 121).

Q6: What cover crop species have you used in the past 5 years?		
	Species	%
Annual ryegrass	*Lolium multiflorum*	26
Cereal rye (a.k.a. winter rye)	*Secale cereale*	96
Crimson clover	*Trifolium incarnatum*	38
Field pea	*Pisum sativum*	31
Red clover	*Trifolium pratense*	44
Spring barley	*Hordeum vulgare*	21
Vetch	*Vicia spp.*	26
Winter triticale	*Triticosecale rimpaui* C. Yen & J.L. Yang (*Secale cereale* × *Triticum aestivum*)	24
Q7: How many years of experience do you have with cover crops?		
	Years of experience	%
	<3	18
	Between 3 and 5	28
	Between 5 and 10	32
	>10	22
Q8: What percentage of the total acreage that you farm/consult was planted to cover crops in the Fall of 2021?		
	% of area	%
	1–20	50
	20–40	22
	40–60	9
	60–80	9
	80–100	10
Q9: Rank the following items considering their relevance when establishing cover crops in your field.		
Rank	**Item**	**Relative importance**[a]
1	Reduce soil erosion	5.09
2	Improve soil structure and/or health	4.83
3	Improve weed management	3.79
4	Improve water infiltration	3.73
5	Improve disease management	2.18
6	Improve insect management	1.38
Q10: Do you agree with the following statement: "The use of cover crops improved overall weed control in my farm/clients' farm".		
		(%)
	Strongly disagree	10
	Disagree	5
	Neither agree nor disagree	17
	Somewhat agree	47
	Strongly agree	21

[a]Relative importance was calculated using Equation (1).

cover crop by the majority of respondents (Q6, Table 2), and considering glyphosate as the most commonly adopted strategy for cereal rye termination (Cornelius & Bradley, 2017; Nord et al., 2012), the predominant method used for cover crop termination before crop planting, as expected, was the application of herbicides, with 92% for soybean and 93% for corn (Q12, Table 3).

The main trigger for cover crop termination time according to respondents was favorable weather conditions suitable for cash crop planting (>50%; Q13, Table 3), followed by cover crop height for both corn and soybean. Regarding the height at which cover crops are typically terminated ahead of crop planting, the survey reveals varied practices among respondents, whereas the majority terminate when cover crops reach

TABLE 3 Sections 3 and 4: Cover crop management ahead of cash crop (soybean and corn; observations [n]: soybean = 105; corn = 104.

Q11: When do you typically terminate your cover crop ahead of cash crop?		
	Soybean (%)	**Corn (%)**
Termination time		
Greater than 14 days before planting	10	17
Between 7 and 14 days before planting	26	22
Between 7 days and planting time	17	17
At planting	10	20
Between planting and 7 days after planting	27	15
More than 7 days after planting	10	9
Q12: What method do you commonly use to terminate the cover crop ahead of cash crop?		
	Soybean (%)	**Corn (%)**
Method		
Herbicides	92	93
Mowing	8	6
Other[a]	12	11
Roller crimper	7	4
Winter kill	23	25
Q13: What have you used as a "trigger" when deciding to terminate your cover crop ahead of cash crop?		
	Soybean (%)	**Corn (%)**
Trigger		
Favorable weather conditions for crop planting	55	60
Cover crop height	32	42
Other[b]	22	17
Soil moisture availability	22	23
Cover crop soil coverage	13	11
Nutrient availability (e.g., nutrient tie-up)	6	12
Q14: What is the approximate height of the cover crop when you terminate it ahead of cash crop?		
	Soybean (%)	**Corn(%)**
cm		
<15	29	23
15–30	49	58
30–47	15	14
>47	7	5
Q15: What impact do you think cover crops have had on your cash crop yield?		
	Soybean (%)	**Corn (%)**
Impact		
Decreased	10	25
No impact	74	54
Increased	16	21

[a]Tillage, forage harvest.
[b]Favorable weather condition for termination.

between 15 and 30 cm (Q14, Table 3), regardless of cash crop planted.

The timing of termination, a variable not easily controlled by farmers, is influenced primarily by favorable weather conditions for planting cash crops rather than cover crop height or proximity to planting time. Given that herbicide use is the main termination method, favorable weather conditions for the application are likely also considered, explaining the lack of major trends observed in termination time as indicated by the respondents (Q11, Table 3). More than 40% of respondents terminated their cover crop at or after planting (i.e., planting green, Reed et al., 2019), regardless of cash crop. The

planting green system aims to increase cereal rye biomass production by delaying termination times, with one of the main benefits being weed suppression (Nunes, Arneson, Wallace, et al., 2023).

An important trade-off of the planting green system is the potential effect on cash crop yield; most farmers perceived cover crops to have no significant impact on soybean yield, whereas opinions on corn yield are more divided (Q15, Table 3), which reflects previous research findings in Wisconsin, while corn is sensitive to high levels of cover crop biomass and may experience yield losses, whereas no to minimal direct effect of properly managed cover crop biomass on soybean yield is typically observed (Grint, Arneson, Arriaga, et al., 2022; Nunes, Arneson, DeWerff, et al., 2023). The diverse array of responses observed in Sections 3 and 4 (Table 3), regarding cover crop termination timing, cover crop height at termination, and perception on cash crop yield (Q11, Q13, Q14, and Q15, Table 2), reflect the different outcomes that respondents are experiencing with cover crops. Particularly concerning to termination timing and cover crop height, respondents may encounter a varied amount of cover crop biomass at termination, highlighting the need for more information on cover crop termination timing and biomass levels. This is crucial as a wide range of cover crop biomass can be achieved in the spring in Wisconsin (<1–10< Mg ha^{-1}, Grint, Arneson, Arriaga, et al., 2022; Nunes, Arneson, Wallace, et al., 2023).

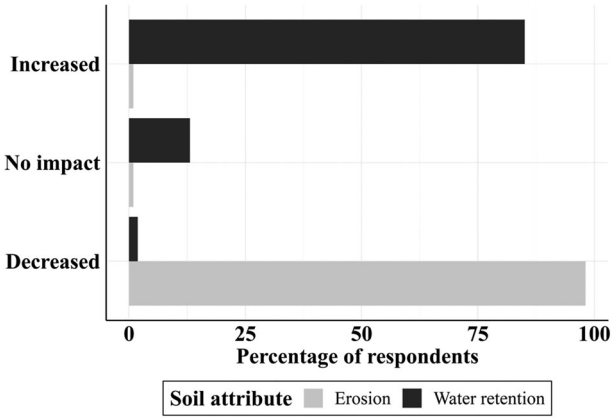


FIGURE 3 Respondents' answer to "What impact do you think cover crops have had overall on these soil attributes in your fields?"

Survey respondents largely reported that cover crops positively influence soil moisture retention throughout the growing season, with 85% noting an increase and only 2% perceiving a decrease (Figure 3; Q16, Table 4), perception that is supported by Reed and Karsten (2022), reporting soils being drier at planting time due to transpiration from living cover crop but wetter throughout the season because of lower evapotranspiration as a result of the dead cover crop mulch on the soil surface (Nunes et al., 2024). Similarly, 98% of respondents acknowledge cover crops' efficacy in reducing

TABLE 4 Section 5: Opinions on cover crop adoption (observations [n] = 107).

Q16: What impact do you think cover crops have had on overall water retention (soil moisture) in your fields?		
	Impact	**%**
	Decreased	2
	No impact	13
	Increased	85
Q17: What impact do you think cover crops have had on overall soil erosion in your fields?		
	Impact	**%**
	Decreased	98
	No impact	1
	Increased	1
Q18: How much of a challenge/concern are each of the following items when including cover crops in your production system?		
Rank	**Item**	**Relative importance**[a]
1	Cash crop establishment	5.66
2	Growing season length	5.37
3	Cover crop management cost	4.99
4	Yield reduction	4.98
5	Soil moisture availability	4.71
6	Cover crop management labor	4.34
7	Pest/disease management	3.57
8	Access to information on cover crops	2.37

[a]Relative importance was calculated using Equation (1).

soil erosion (Figure 3; Q17, Table 4), emphasizing their significant role in erosion control (Kaspar et al., 2001; Krutz et al., 2009).

When considering challenges associated with integrating cover crops into production systems, respondents ranked various factors by their perceived level of difficulty or concern. Cash crop establishment and growing season length emerged as the two primary concerns, followed closely by cover crop management cost, subsequent cash crop yield reduction, soil moisture availability, and cover crop management labor (Q18, Table 4). The proximity of the relative importance observed for this ranking, particularly from the third to the sixth item, indicates that there is no single reason that stands out as the most challenging or concerning. Rather, this ranking reflects the complex network of benefits and trade-offs farmers face when adopting cover crops, particularly when delaying cover crop termination until or after cash crop planting (Grint, Arneson, Arriaga, et al., 2022; Reed et al., 2019).

This survey highlights the importance of understanding the stakeholder's perceptions in developing effective cover crop management strategies. While cover crops offer valuable benefits, their adoption and management present challenges in balancing weed suppression with operational efficiency and cash crop establishment. Research needs identified in the survey include evaluation of weed suppression under different biomass levels and optimization of cover crop termination timing to balance weed suppression and cash crop yield. Surveys like this will continue to guide research efforts and support the development of sustainable weed management practices, benefiting farmers in Wisconsin and beyond.

AUTHOR CONTRIBUTIONS

Guilherme Chudzik: Conceptualization; data curation; formal analysis; investigation; methodology; project administration; visualization; writing—original draft. **Jose J. Nunes**: Conceptualization; methodology; writing—review and editing. **Nicholas J. Arneson**: Conceptualization; methodology; supervision; writing—review and editing. **Grace Arneson**: Methodology; writing—review and editing. **Shawn P. Conley**: Supervision; writing—review and editing. **Rodrigo Werle**: Conceptualization; funding acquisition; investigation; methodology; project administration; supervision; resources; validation; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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