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Maxwel C. Oliveira
University of Wisconsin-Madison, max.oliveira@wisc.edu

Liberty Butts
University of Nebraska - Lincoln, libertybutts16@gmail.com

Rodrigo Werle
University of Wisconsin-Madison, rwerle@wisc.edu

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Article

Assessment of Cover Crop Management Strategies in Nebraska, US

Maxwel C. Oliveira [1], Liberty Butts [2] and Rodrigo Werle [1,*]

[1] Department of Agronomy, University of Wisconsin-Madison, 1575 Linden Drive, Madison, WI 53706, USA; max.oliveira@wisc.edu

[2] Department of Agronomy and Horticulture, University of Nebraska-Lincoln, West Central Research and Extension Center, North Platte, NE 69101, USA; libertybutts16@gmail.com

* Correspondence: rwerle@wisc.edu

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Abstract: Adoption of cover crops has the potential to increase agricultural sustainability in the US and beyond. In 2017, a survey was conducted with Nebraska stakeholders in an attempt to evaluate current cover crop management strategies adopted in soybean (*Glycine max* [L.] Merr.), field corn (*Zea mays* L.), and seed corn production. Eighty-two Nebraska stakeholders answered the survey, of which 80% identified themselves as growers. Eighty-seven percent of respondents manage cover crops, and the average cover crop ha planted on a per farm basis is 32%. The primary method of establishing cover crops following soybeans and field corn is drilling. In seed corn, interseeding is the main seeding strategy for cover crop establishment. Cereal rye (*Secale cereale* L.) appeared as the most adopted cover crop species (either alone or in mixtures with radish [*Raphanus sativus* L.] or hairy vetch [*Vicia villosa* Roth]). Over 95% of respondents utilize herbicides for cover crop termination in the spring before crop planting. Glyphosate is used by 100% of survey respondents that use herbicides for cover crop termination. The major observed impacts of incorporating cover crops into a production system according to survey respondents are reduced soil erosion and weed suppression. According to 93% of respondents, cover crops improve weed control by suppressing winter and/or summer annual weed species. The biggest challenge reported by cover crop adopters is planting and establishing a decent stand before winter. According to the results of this survey, there are different management strategies, positive outcomes, and challenges that accompany cover crop adoption in Nebraska. These results will help growers, agronomists, and researchers better guide cover crop adoption, management, and future research and education needs in Nebraska and beyond.

Keywords: cereal rye (*Secale cereale* L.), corn (*Zea Mays* L.); conservation agriculture; soybean (*Glycine max* [L.] Merr.); weed suppression

1. Introduction

Nebraska is a top field crop producer state in the US. In the last century, the diversity of crops in Nebraska was high in the 1950s/60s, with corn (*Zea mays* L.), sorghum (*Sorghum bicolor* [L.] Moench), alfalfa (*Medicago sativa* L.), wheat (*Triticum aestivum* L.), oats (*Avena sativa* L.), and soybean (*Glycine max* [L.] Merr.) comprising the landscape; however, crop diversity has decreased throughout the decades [1]. Corn has always been a dominant crop in Nebraska and the state is amongst the largest field corn, seed corn, and popcorn producers in the US. Soybean is the second-most grown crop in the state. The soybean area increased in Nebraska, replacing sorghum and oats after the 1960s [1]. The summed planted area of corn and soybean in Nebraska was 6.1 million ha in 2018 [2], which represents 30% of the state territory.

Corn and soybean rotation is a commonly adopted practice among Nebraska growers, especially in the eastern part of the state. The dependence on corn and soybean rotation, in part, reduced crop diversity and imposed a strong selection pressure on Nebraska's agroecosystems. As a result, pest outbreaks and N runoff [3] are some of the issues of Nebraska agriculture. Integrated crop, nutrient, and pest management strategies have been recommended to increase sustainability in agroecossystems [4,5]. Amongst the sustainable strategies, conservation practices, including no-till and cover crops, gained growers interest and adoption in the last decades [6,7].

The use of glyphosate and the wide adoption of glyphosate-resistant crops (e.g., corn and soybean) contributed to the shift from conventional tillage to no-till cropping systems [8]. It is estimated that over 50% of growers in the US Midwest have adopted no-till as a standard practice [9]. The benefits of using conservation practices has led growers to have an increased interest in cover crops [10]. A well-established cover crop stand can provide several benefits to agroecosystems, including reduced soil erosion, increased soil health, and weed suppression [11,12]. For example, it is estimated that the use of cover crops in the Midwest has the potential to reduce 20% of NO_3 in the Mississippi River [13]. However, in Nebraska and across the US Midwest, growers are facing challenges to implementing cover crops in their systems. Some of the challenges for cover crop adoption include a short growing season window, cover crop selection, planting, termination strategy and timing, and farm operational logistics [14,15].

In a recent survey, cover crops were listed fifth on priority weed research and extension topics in Nebraska [16], indicating growers' interest in learning more about cover crop management. Therefore, there is a need to document Nebraska stakeholders' experiences and perceptions regarding cover crops, and surveys can be a useful method for obtaining this information. In addition, survey results can demonstrate opportunities and challenges through shared collective knowledge and experiences to improve on farm decision making processes. Surveys have become an important tool to evaluate and document trends in agriculture. For example, several surveys have documented the impact of tillage [9], pesticide application [17–19], and weed management [16,20] in the US Midwest. Moreover, surveys have documented the adoption of cover crops in the US [21,22]. It was shown that crop diversity in a farm operation was the most important factor for cover crop adoption [21]. Therefore, a cover crop survey focused on agronomic management practices was conducted with Nebraska stakeholders (growers, agronomists, industry representatives, and crop consultants). The objective of the survey was to evaluate cover crop management strategies and challenges in soybean, field corn, and seed corn cropping systems of Nebraska.

2. Methods

A paper copy survey was handed out during the 2017 Cover Crops Conference at the Eastern Nebraska Research and Extension Center, Ithaca, Nebraska, on 14 February 2017.

The survey comprised eight sections (Figure 1). Questions focused on respondent demographics (Q1–4, Figure 1A); cover crop management during the corn (Q5–7, Figure 1B), seed corn (Q8–10, Figure 1C), and soybean growing season (Q11–13, Figure 1D); cover crop management going into a corn (Q14–15, Figure 1E), seed corn (Q16–17, Figure 1F), and soybean (Q18–19, Figure 1G) growing season; and general questions about cover crop management in Nebraska (Q20–24).

Survey data were entered into an excel spreadsheet. Survey data were sorted, filtered, and analyzed using *pipe*, *select*, *filter*, *summarize*, and *count* in the tidyverse [23] package in R statistical software [24]. For most questions, results are presented in two fashions: (1) percentage of respondents answering, and (2) percentage of ha represented. Not every respondent answered every question.

The percentage of cover crop managed area for each survey respondent was calculated with the equation:

$$Y = \frac{C}{T} * 100,$$

where Y, C, and T represent the percentage area planted to cover crops, ha planted with cover crops (Q4, Figure 1), and the total ha managed (Q3, Figure 1) by each survey respondent, respectively.

2017 COVER CROP PRODUCTION SURVEY

Name: ____________________ Phone: ____________________ Email: ____________________

A. DEMOGRAPHICS:

Q1 County/State: ____________________

Q2 What is your role: GROWER, CONSULTANT, INDUSTRY, OTHER? ______________

Q3 How many acres do you farm/manage? __________

Q4 How many acres have cover crops? __________

B. DURING CORN GROWING SEASON

Q5 What crop stage do you plant cover crops? ____________________

Q6 How do you plant cover crops: HAGIE INTERSEEDER, AERIAL SEEDING, DRILL, OTHER? ______________

Q7 What cover crop species do you plant? ____________________

C. DURING SEED CORN GROWING SEASON:

Q8 What crop stage do you plant cover crops? ____________________

Q9 How do you plant cover crops: HAGIE INTERSEEDER, AERIAL SEEDING, DRILL, OTHER? ______________

Q10 What cover crop species do you plant? ____________________

D. DURING SOYBEAN GROWING SEASON:

Q11 What crop stage do you plant cover crops? ____________________

Q12 How do you plant cover crops: HAGIE INTERSEEDER, AERIAL SEEDING, DRILL, OTHER? ______________

Q13 What cover crop species do you plant? ____________________

E. GOING INTO A CORN SEASON:

Q14 When do you terminate cover crops? ____________________

Q15 How do you terminate cover crops: HERBICIDES, ROLLER/CRIMPER, MOWER, TILLAGE, OTHER? _______

F. GOING INTO A SEED CORN SEASON:

Q16 When do you terminate cover crops? ____________________

Q17 How do you terminate cover crops: HERBICIDES, ROLLER/CRIMPER, MOWER, TILLAGE, OTHER? _______

G. GOING INTO A SOYBEAN SEASON:

Q18 When do you terminate cover crops? ____________________

Q19 How do you terminate cover crops: HERBICIDES, ROLLER/CRIMPER, MOWER, TILLAGE, OTHER? _______

H. GENERAL QUESTIONS:

Q20 What major change have you observed in your operation since cover crops were introduced:_________

Q21 What is the biggest challenge regards having cover crops in your operation:____________________

Q22 Have cover crops improved weed control in your operation: YES or NO

If so, what weed species have you observed enhanced control? ____________________

Q23 When using herbicides for cover crop termination, what herbicide do you use: GLYPHOSATE, Liberty, Gramoxone, 2,4-D, other? ______________

Q24 When do you include soil residual herbicides in the tank-mix: COVER CROP TERMINATION, CROP PLANTING, BOTH, OR DON'T USE RESIDUAL PRODUCT?

Suggestion for future cover crop research: ____________________

Figure 1. The survey questionnaire conducted with 82 individuals during the 2017 Cover Crops Conference (14 February 2017) held at the Eastern Nebraska Research and Extension Center, Ithaca, Nebraska.

The correlation between *T* and *C* as well as the correlation between *T* and *Y* were evaluated with the Pearson's analysis using the *cor.test* function in the R statistical software [24]. The correlation values range from −1 to 1, where 1 represents the maximum positive linear correlation, 0 represents no linear correlation, and −1 is the maximum negative correlation. The Pearson's analysis tests the hypothesis that the correlation between two variables is different from 0. A *p*-value > 0.05 indicates no correlation between two variables.

3. Results and Discussion

3.1. Description of Survey Respondents

A total of 82 individuals, primarily from the eastern part of Nebraska where soybean and corn are the major crops, participated in the survey. Sixty-six respondents identified themselves as growers (80%) and seven as consultants, industry representatives, or agronomists (9%). The majority (87%) of respondents integrate cover crops into their cropping systems (n = 82). The total area managed by respondents in this survey was 149,330 ha (n = 67), with 24,240 ha planted with cover crops (n = 67), representing 16% of their total managed area. Most of survey respondents manage cover crops in eastern Nebraska, and growers manage 7681 ha of cover crops (Figure 2). Nearly 50% of the cover crop ha are managed by survey respondents identified as growers and located in Butler County, Nebraska, where the conference was held (Figure 2).

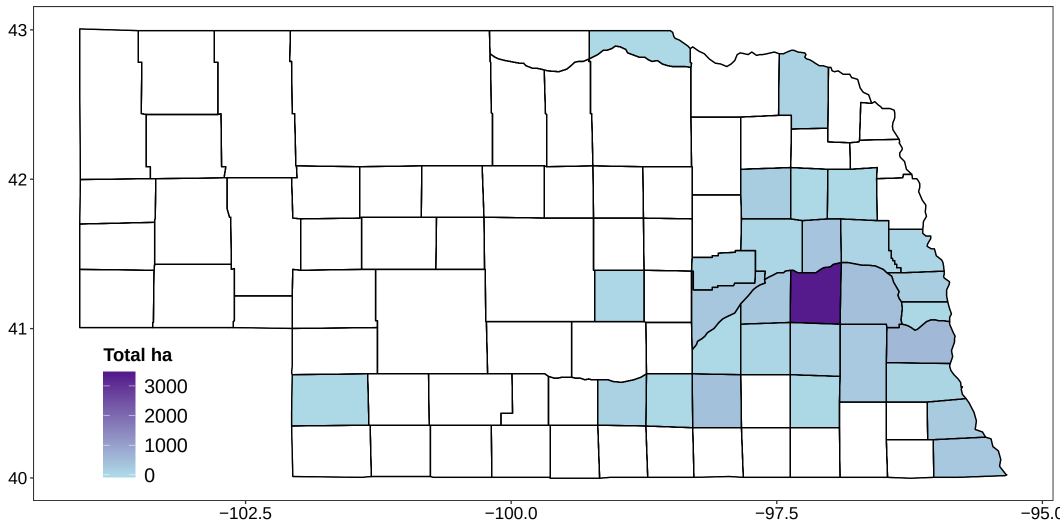

Figure 2. Map of Nebraska counties with the sum of total cover crop ha managed by survey respondents identified as growers. The dark purple color represents Butler County, where the 2017 Cover Crops Conference took place.

A positive correlation was detected between *T* and *C* (Figure 3A), indicating that larger growers manage more cover crop ha. However, a negative correlation was detected between *T* and *Y* (Figure 3B), indicating that larger farmers tend to plant a smaller proportion of their total ha with cover crops, compared to smaller operations. Overall, growers reported managing cover crops on 32% of their ha, varying from 2.5 to 100% (Figure 3B).

From 2001 to 2005, 11% of corn belt growers adopted cover crops [22]. In an early 2000s survey, over 50% of growers would have planted cover crops if cost-sharing was available [21]. Recently, a survey with 2012 growers across the US indicated that 88% of respondents planted cover crops in 2016 [25]. The survey also showed that the area planted with cover crops increased nearly 60% from 2014 to 2016. Although these data originated from different surveys, there is a clear growing trend of cover crops adoption in the US. The rise in cover crop adoption is possible due to a combination of several factors, such as increased crop diversity, popular pressure for adoption of sustainable agricultural production, cost reduction, and policy incentives (e.g., government cost-sharing and conservation programs). Further research is necessary to investigate and quantify the local and regional impacts of increased cover crop adoption in US cropping systems.

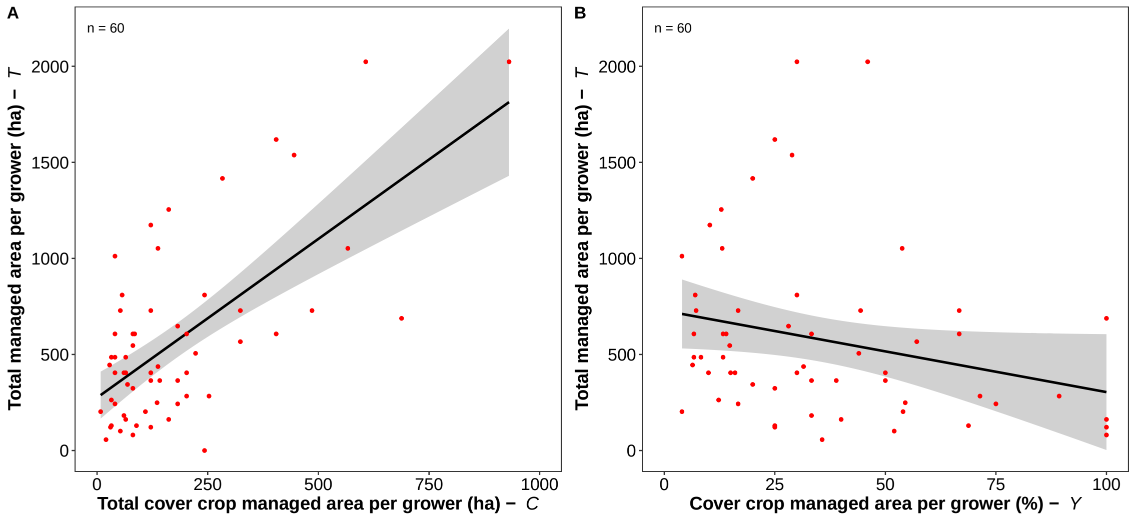

Figure 3. Correlation between per grower total ha managed and (**A**) the total ha planted to cover crops and (**B**) the % ha planted to cover crops. In (**A**), the correlation is 0.66 (lower confidence interval [CI] 0.49–upper CI 0.78) with p-value= 0.00. In (**B**), the correlation is −0.25 (lower CI −0.48–upper CI 0.01) with p-value= 0.05. The black line represents the linear trend and the shaded area the 95% CI.

3.2. Cover Crop Establishment

According to survey respondents, cover crop establishment in Nebraska varies with the cropping system. In soybean seasons, 27% of survey respondents seed their cover crops prior to the soybean harvest, while 73% seed after the crop harvest (n = 56, Table 1A). Drilling after crop harvesting is the main method of cover crop establishment in soybean years (72%, Table 1B), followed by aerial seeding (28%, n = 53). No respondents interseed cover crops in soybean. Cereal rye (*Secale cereale* L.) is used by 43%, while a cover crop mix (cereal rye plus oats, radish [*Raphanus sativus* L.], and/or hairy vetch [*Vicia villosa* Roth]) is used by 57% of the respondents (n = 57, Table 1C).

In field corn seasons, 27% of respondents seed cover crops prior to the corn harvest, while 73% seed after the crop harvest (n = 59, Table 1A). Drilling after corn harvesting is the main strategy for planting cover crops (66%), followed by aerial seeding (26%, typically done when the crop starts to mature), and interseeding (8%, n = 61, Table 1B). Cereal rye is used by 47% of the respondents, while a mix of species is used by 53% (cereal rye plus radishes, and/or vetch, n = 62, Table 1C).

In field corn and soybean, drilling cover crops after the crop harvest in the fall is a common management strategy among survey respondents in Nebraska. Drilling cover crops has long been a management strategy in the US Midwest. In the 2000s, a survey in Illinois, Indiana, Iowa, and Minnesota showed that nearly 70% of cover crop growers establish cover crops using drilling after the grain crop harvest [22]. The desired seed and soil contact for seed germination is the main benefit of drilling cover crops [26]. Despite drilling after the harvest being a common practice, researchers have demonstrated the value of aerial seeding or interseeding cover crops prior to crop harvest [27,28]. A benefit of aerial seeding or interseeding is earlier cover crop establishment, especially *Brassica* and legume species, which require earlier planting to produce a satisfactory amount of biomass in the fall.

Table 1. Cover crop management strategies in Nebraska according to survey respondents.

	Soybean	Field Corn	Seed Corn
		%	
A. Seeding Time			
prior to crop harvest	27	27	85
after crop harvest	73	73	15
n [1]	56	59	13
B. Seeding strategy			
interseed	0	8	77
aerial	28	26	15
drill	72	66	8
n	53	61	13
C. Cover crop selection			
cereal rye	43	47	0
multiple species mix [2]	57	53	100
n	47	62	13
D. Cover crop termination time			
two weeks prior to planting	46	73	100
one week prior to planting	26	12	0
at planting	28	15	0
n	35	40	7
E. Cover crop termination strategy			
herbicides	96	95	100
non-herbicides	4	5	0
n	46	55	11

[1] n: number of respondents. [2] multiple species mix: cereal rye plus oats, radishes, turnips, and/or hairy vetch.

Eighty-five percent of survey respondents seed cover crops prior to the seed corn harvest, while 15% plant after the harvest (n = 13, Table 1A), which is a different strategy from soybean and field corn seasons. Interseeding cover crops is the main seeding practice in seed corn years (77%), followed by aerial seeding (15%) and drilling (8%, n = 13, Table 1B). Interseeding cover crops, after seed corn male rows are destroyed and using a seed spreader benefits the establishment of cover crops, especially legumes and brassicas. As a result, a mix of species is used by 100% of the respondents in seed corn systems (radishes, turnips [*Brassica rapa* L.], and cereal rye mix, n = 13, Table 1C).

A standard practice among survey respondents is planting cereal rye alone or in mixtures with brassicas and/or legumes as cover crops in soybean, field corn, and seed corn. The use of cover crop mixtures is likely to increase agroecosystem diversity but may not provide benefits beyond cover crop monocultures [29]. It has been documented that fall-planted cereal rye monocultures and cereal rye mixtures with brassicas and/or legumes produced the highest amount of biomass compared to other cover crop monocultures, and cereal rye in mixtures accounted for nearly 80% of spring biomass [29]. A higher amount of cover crop biomass is positively correlated with weed suppression, nitrate leaching prevention, and aboveground N, C/N ratio but negatively impacts early-season inorganic N availability to subsequent crops (e.g., corn) [30].

In general, cereals (e.g., oats and/or rye) and legumes (e.g., hairy vetch and/or crimson clover [*Trifolium incarnatum* L.]) are a good combination for producing large amounts of biomass cover and fixing N, respectively. The low C/N ratio of legume cover crops favors decomposition and N mineralization relative to grass cover crops [11]. The seed mixture proportion would depend on the ultimate goal when managing a cover crop. For example, with cereal rye/hairy vetch mixtures, a higher proportion of the cereal is recommended for soil cover and weed suppression but higher hairy vetch is recommended for N accumulation in the soil [31].

3.3. Cover Crop Termination and Herbicide Programs

Survey respondents were asked when and how they terminate cover crops when soybean, field corn, and seed corn are planted as the subsequent crop. One hundred percent terminate cover crops two weeks prior to seed corn planting (n = 7, Table 1D), whereas 73% and 46% of respondents adopt such a practice when field corn and soybeans are planted as the subsequent crop, respectively. Terminating cover crops at least two weeks prior to planting is a commonly recommended practice [32]. For example, herbicide applications in early April rather than early May provided the best control of winter wheat, cereal rye, annual ryegrass (*Lolium multiflorum* Lam.), crimson clover, hairy vetch, and Austrian winter pea (*Pisum sativum* L.) cover crops [33]. However, early terminated cover crops may not yield significant amounts of biomass in the spring. High cover crop biomass is needed for weed suppression and for proving N to the agroecosystem [34]. It was reported that delaying for spring termination of hairy vetch in two weeks significantly increased N for the subsequent crop [35]. Therefore, there are trade-offs to be considered when deciding the timing for termination, which depends on grower's primary goal(s) for the cover crop.

Termination is an important component for integrating cover crops in cropping-systems. Despite non-chemical strategies for terminating cover crops, including tillage and roller crimper [36–39], more than 95% of survey respondents use herbicides (Table 1E). Therefore, it is likely that the majority of survey respondents manage conventional cropping systems (e.g., no organic farmers represented in the survey). When herbicides are used, 100% of survey respondents spray glyphosate, alone (44%) or in mixtures (56%; n = 66, Figure 4A). Glyphosate tank-mixes with 2,4-D, 2,4-D + paraquat (e.g., Gramoxone®), glufosinate (e.g., Liberty®), and/or other herbicides (e.g., saflufenacil [Sharpen®] or carfentrazone [Aim®]) are used by 41%, 9%, 3%, and 3% of the survey respondents, respectively.

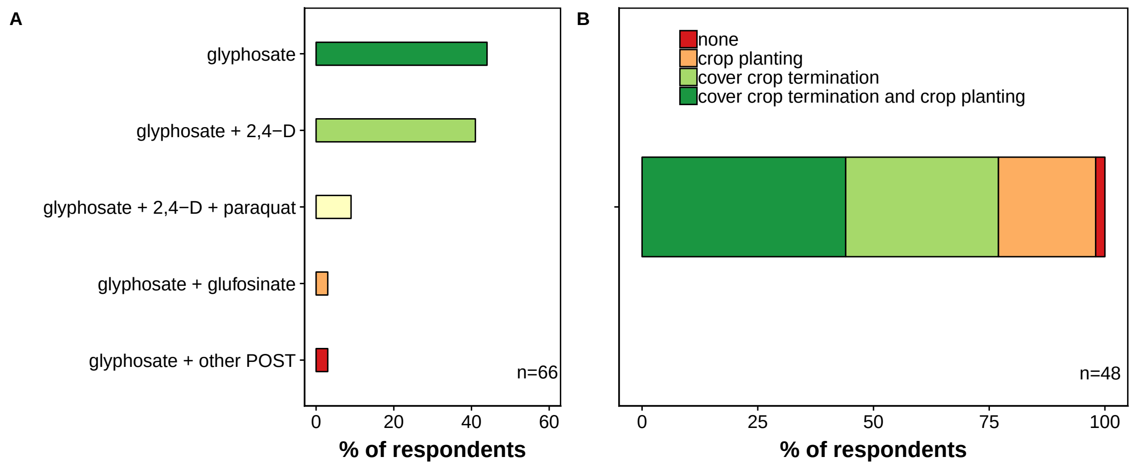

Figure 4. Herbicide programs used for cover crop termination (**A**) and timing for pre-emergence herbicide application (**B**) according to Nebraska survey respondents.

Our survey shows a strong reliance of Nebraska growers on glyphosate for cover crop termination. The use of glyphosate alone may not provide effective cover crop termination, especially when cover crops are at advanced stages and/or when cover crop mixtures are established. It was documented that glyphosate alone provided nearly complete cereal rye control but poor Austrian winter pea, crimson clover, and hairy vetch control [40]. The enhanced control of cover crop mixtures occurred when glyphosate was tank-mixed with other herbicides [40]. For example, glyphosate tank-mixed with 2,4-D or dicamba provided nearly 30% higher hairy vetch control than glyphosate alone [33]. These results highlight that when growers use herbicides for terminating cover crops, glyphosate is a excellent option for cereal rye monoculture, but glyphosate combined with other herbicide site(s) of action is a better option when legumes and other species (e.g., winter annual weed species) are established.

The use of pre-emergent (PRE) herbicides is a common strategy for weed management in Nebraska. The most common PRE herbicide treatment used by Nebraska growers at planting is atrazine + mesotrione + *S*-metolachor and cloransulan-methyl + sulfentrazone for field corn and soybean, respectively [16]. Forty-four percent of survey respondents apply PRE herbicides at cover crop termination and crop planting, 33% at cover crop termination, 21% at crop planting, and only 2% do not use PRE herbicides (n = 48, Figure 4B). However, cover crop residue may intercept PRE herbicides, reducing their effectiveness [41]. For example, when not reaching the soil, any herbicide may dissipate (volatilization) and/or degrade (via photodegradation or by microorganisms). When using cover crops and PRE herbicides, a timely rainfall is needed for herbicide incorporation and activation in soils [42]. Nonetheless, well-established cover crops suppress weeds, and PRE herbicides are necessary to provide long soil residual activity, which helps to control early- and late-germinating weed species. Additional research is needed to better understand the interactions among cover crops, soils, and PRE herbicides.

3.4. Impact of Cover Crops in Production Systems

Cover crops have the potential to provide direct and indirect benefits to cropping systems (e.g., increase soil organic matter and reduce soil erosion). However, measuring cover crop services to agroecosystems is difficult [12]. In Nebraska, most survey respondents reported that the major benefit of cover crops is reduction of soil erosion (45%, n = 42, Figure 5). Cover crop roots and aboveground biomass function as a physical barrier protecting soils from wind and water erosion [11,43].

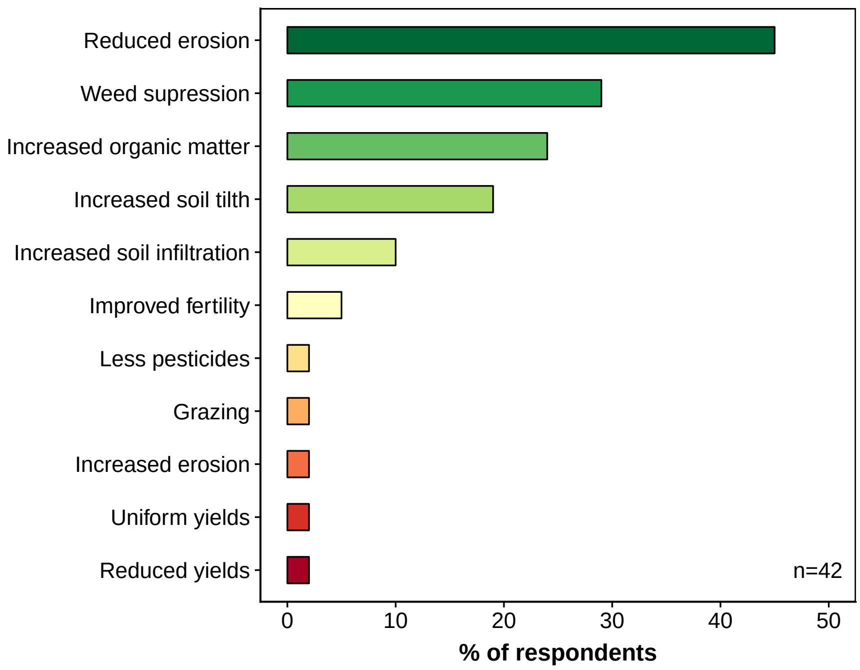

Figure 5. Major observed change(s) after adoption of cover crops in agroecosystems according to Nebraska survey respondents.

Increased soil organic matter (24%), increased soil tilth (19%), and increased soil water infiltration (10%) are also perceived services that cover crops provide to Nebraska cropping systems (Figure 5). These services increase soil health, but their benefits occur with the long-term adoption of cover crops [12]. Although legume cover crops can provide significant amounts of N-enriched biomass and nutrient cycling [44], only five percent of survey respondents mentioned that cover crops improved soil fertility in their operations. N accumulation is strongly correlated to the amount of legume biomass [11], which depends on stand, winter overkill, and termination timing.

After reduced soil erosion, weed suppression was the second most common reported benefit of cover crops according to survey respondents (29%, Figure 5). A meta-analysis reported that cover crops can provide early-season weed control comparable to chemical and mechanical weed control strategies [45]. For example, cereal rye used as cover crops reduced density and biomass of henbit (*Lamium amplexicaule* L.) and horseweed *(Conyza canadensis* [L.] Cronquist) by 90% in Nebraska [46]. In addition, cereal rye provided near 85% suppression of Palmer amaranth (*Amaranthus palmeri* [S.] Watson) in cotton [47]. Horseweed and Palmer amaranth represent two of the most difficult-to-control weed species, mostly because of herbicide resistance evolution [48]. Therefore, well-established cover crops have the potential to suppress hard-to-control weed species in Nebraska and beyond. Further investigating the impact of cover crops on weed demographics and long-term seed bank density and viability may provide valuable information regarding cover crop adoption.

Additional described benefits were reduced pesticide use, increased grazing opportunity, and uniform yields (2%, Figure 5). A few respondents reported reduced crop yields and increased erosion where cover crops have been adopted (2%; Figure 5). Few respondents reported a reduction of pesticide usage where cover crops are adopted. Further studies should investigate whether and how the integrated management of cover crops can reduce the reliance and use pattern of pesticides.

Ninety-three percent of survey respondents answered that cover crop adoption improved weed control in their operations (n = 54, Figure 5). According to survey respondents, the most effectively suppressed weeds are winter annual (79%), followed by late-season summer annual (55%), and early-season summer annual species (26%, n = 38, Figure 5B). Cover crops promote direct competition with winter annual and suppression of summer annual weed species via residue acting as a physical barrier during emergence and seedling establishment. Therefore, cover crops have the potential to suppress common weed species present in Nebraska cropping systems, including downy brome (*Bromus tectorum* L.), horseweed, waterhemp (*Amaranthus tuberculatus* [Moq.] Sauer), Palmer amaranth, and giant ragweed (*Ambrosia trifida* L.) [49,50].

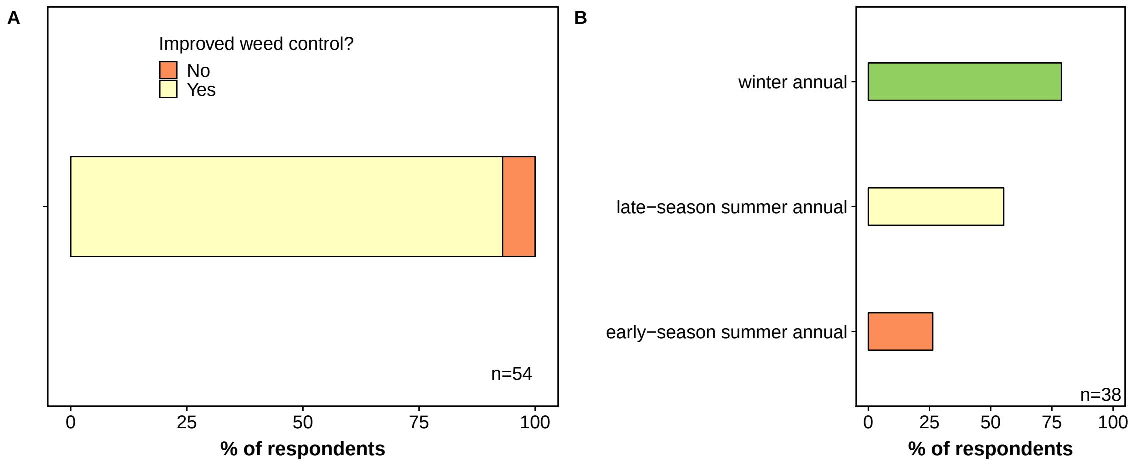

Figure 6. Cover crop improvement of weed control (**A**) and groups of annual weed species effectively suppressed by cover crops (**B**) according to Nebraska survey respondents.

3.5. Challenges With the Incorporation of Cover Crops

According to survey respondents who adopt cover crops, the biggest challenge has been planting and establishing stands before winter, due to a short growing season and time and/or equipment availability (56%, Figure 6. In the upper US Midwest, the lack of a growing season left after grain crop harvest, timely rainfall events, and winter kill are the main constraints for cover crop establishment in the fall. Moreover, planting cover crops often requires extra equipment [12]. As previously discussed, early seeding of cover crops via aerial seeding could be an alternative strategy to enhance biomass production in the fall. However, the cost of flying, poor seed–soil contact, and a lack of reliance are the main challenges of this strategy. Thus, the aerial seeding of cover crops is a potential research area that deserves more attention.

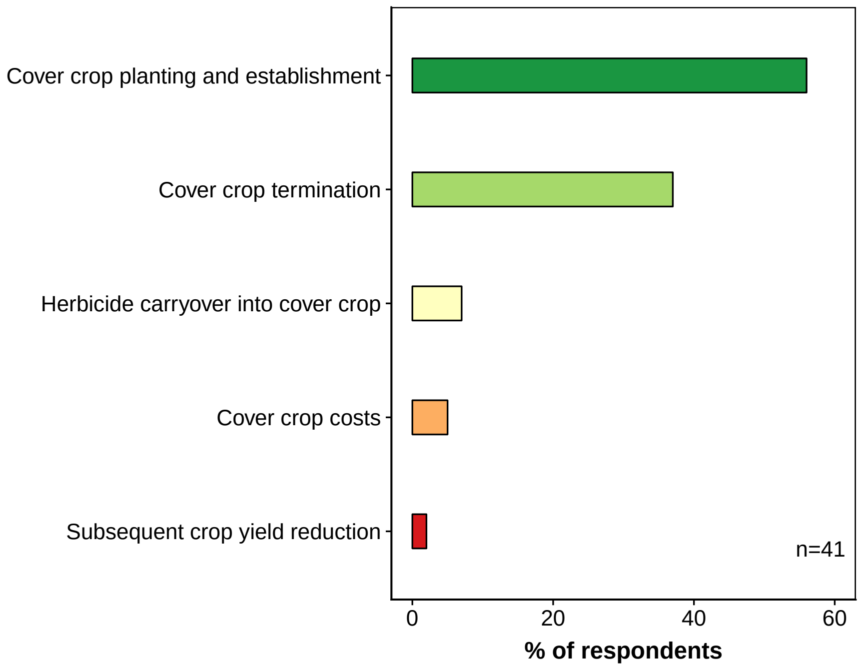

Figure 7. Challenges for adopting cover crops according to survey respondents of Nebraska.

The termination of cover crops in the spring was ranked as the second biggest challenge (37%, Figure 6). A poorly controlled cover crop could become a weed problem, reducing subsequent crop establishment and yield potential. In addition, late-terminated cover crops are likely to increase insect pest pressure [51] and host seedling pathogens [52,53]. The incidence of seedling disease (e.g., *Pythium* spp.) and low corn emergence occur when cover crops (cereal rye) were late terminated [54].

The use of soil residual herbicides for weed control in Nebraska is a barrier for cover crop (e.g., brassica and radish) establishment in the fall according to 7% of survey respondents (Figure 5B). To enhance waterhemp and Palmer amaranth control, growers are advised to overlap soil residual herbicides tank-mixed with other POST herbicides. Some herbicides have extended residual activity in the soil and can lead to subsequent cover crop failure. For example, herbicide products commonly used in corn and/or soybeans, such as pyroxasulfone, imazethapyr, fomesafen, and flumetsulan are likely to have negative impacts on cover crop establishment in the fall [55].

The costs associated with incorporating cover crops is a challenge for 5% of survey respondents. According to a survey, nearly 50% of cover crop growers paid from \$25 to 50 ha^{-1} for cover crop seeds [25]. Higher seed costs are related to the inclusion of legume species in the mix. However, growers can obtain a return on the investment by using cover crops as forages, reducing the amount of fertilizer by using cover crops to cycle nutrients, and through the suppression of weeds in their operation (e.g., reduced herbicide reliance). It is documented that growers who received government cost-share and used cover crops for livestock grazing or forage typically derived positive net returns from cover crops [56]. Other benefits such as increased soil health and reducing farming inputs are difficult to measure and likely to be viewed as long-term investments [12]. The profitability of cover crops varies according to the ultimate goal of cover crop growers.

Two percent of survey respondents reported crop yield reduction when adopting cover crops (Figure 7). A meta-analysis over 65 years of research studies showed that if properly managed, fall-seeded cover crops do not reduce corn yields [34]. For example, the incorporation of fall-planted cereal rye after corn harvested in rotation with soybean resulted in comparable soybean yields where no cover crops were grown [57]. Therefore, cover crops should not reduce yields if managed according to the best management practices, especially under timely termination prior to crop establishment.

4. Conclusions

The 2017 Nebraska cover crop survey highlights that small growers are more likely to plant a higher percentage of their managed ha with cover crops. Most cover crops established in soybean and field corn are drilled after crop harvest, whereas in seed corn, cover crops are interseeded prior to harvest. All respondents managing seed corn adopt a multi-species mix, but respondents managing soybean and field corn select cereal rye alone or in a mixture with other species. Most respondents terminate cover crops with herbicides two weeks prior to planting the subsequent crop. The main benefits of cover crops are improved soil health and weed suppression. Establishment in the fall and termination in the spring are the main challenges for cover crop adopters in Nebraska. There are many ways cover crops can be incorporated in cropping systems, and the results of this survey highlight the main strategies, benefits, and challenges observed by cover crop adopters in Nebraska. When deciding how best to use cover crops, it is important to consider the ultimate goal. The goal could be to increase soil organic matter, increase nutrient availability to subsequent crops, reduce soil compaction, supply forage for livestock, and/or to suppress weeds. Results presented herein may aid stakeholders improve their management practices as well as provide insight regarding research and extension priorities moving forward.

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Abbreviations

The following abbreviations are used in this manuscript:

C	carbon
ha	hectares
N	nitrogen
US	United States of America
n	number of respondents

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