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Impact of planting green on soil properties under irrigated no-till soybean

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Abstract

Planting green refers to the practice of planting a row crop into an actively growing cover crop (CC) and terminating it at or after row crop planting. Planting green could have more beneficial impacts on soil properties, erosion control, nutrient cycling, weed suppression, and other soil ecosystem services because it allows greater CC biomass accumulation than early-terminated CC. The objectives of this 2-year study were to evaluate the impact of planting green on soil properties (bulk density, wet aggregate stability, sorptivity, particulate organic matter, organic matter, nutrients, and others) and soybean (*Glycine max* L.) yield in an irrigated no-till soybean system in south-central Nebraska. Treatments were cereal rye (*Secale cereale* L.) CC terminated 2 weeks before planting (2WBP), CC terminated 2 weeks after planting (2WAP) soybean, and no CC. On average, CC produced 2.35 Mg ha^{-1} of biomass for 2WBP and 12.03 Mg ha^{-1} for 2WAP. Both 2WBP and 2WAP reduced N concentration by 48% (31.10 vs. 59.70 mg kg^{-1}) but had no effect on other soil properties compared with no CC. Despite the abundant CC biomass production, terminating 2WAP had little to no effect on most soil properties in the short term (2 years). Wet aggregate stability increased as CC biomass production increased, while soil sorptivity (initial water infiltration) increased as wet aggregate stability increased. CC termination timing had inconsistent effects on soybean yield. In general, after 2 years, planting green had no effect on most soil properties or soybean yield, warranting long-term studies on this topic.

1 | INTRODUCTION

In 2021, 35.4 million ha of soybean were planted in the United States, 2.2 million of which were in Nebraska (USDA-NASS, 2022). Among the 2.20 million ha of soybean grown in Nebraska, about 50% (1.11 million ha) are irrigated and the rest are rainfed (USDA-NASS, 2022). Thus, supporting soybean production via maintenance or improvement in soil health, fertility, and productivity is vital. The introduction of cover crops (CCs) in soybean production systems can be a potential strategy for improving soil properties and productivity. However, the literature shows that CCs could have inconsistent effects on soil properties and crop yields, particularly in the short term (Blanco-Canqui et al., 2015; Finney et al., 2017; Poeplau & Don, 2015; Vukicevich et al., 2016).

Abbreviations: 2WAP, 2 weeks after planting; 2WBP, 2 weeks before planting; CC, cover crop.

One of the leading factors that may affect CC benefits is CC biomass production (Ruis et al., 2019). Previous studies found that increased CC biomass production can result in improved bulk density (Duiker & Curran, 2005), water infiltration (Blanco-Canqui et al., 2015), and water holding capacity (Basche et al., 2016) and increased soil organic carbon (C) accumulation (Poeplau & Don, 2015), among others. Cover crop management such as CC planting dates (Ruis et al., 2020) and termination dates (Ruis et al., 2019) could affect the amount of CC biomass produced, provided that other factors such as climate are favorable. Thus, lengthening the CC growing season via late termination may be a strategy to increase CC biomass accumulation (Ruis et al., 2019). For example, one study found that CC accumulated about 1.75 Mg ha^{-1} of biomass for every 10 days of extra CC growth in a humid and mild region (Nord et al., 2012).

While several studies have evaluated the effect of CC planting and termination dates on soil properties and crop yields (Koehler-Cole et al., 2020; Ruis et al., 2017, 2020), little is known about the implications of "planting green" on soil properties and crop yields (Acharya et al., 2022). Planting green is defined as planting a row crop into an actively growing CC, such as cereal rye, and terminating the CC at the time of main crop planting or after (Reed et al., 2019). Planting green could have more positive impacts on soil properties compared with typical termination times due to the increased amount of biomass resulting from terminating the CC after the main crop planting. For example, in the Midwest United States, CCs are typically terminated in the spring 2 or 3 weeks before planting corn (*Zea mays* L.) or soybean. The early termination limits CC growth and thus biomass production due to cold temperatures during early spring (Oliveira et al., 2019). Research on the effects of different CC termination dates, including planting green, on soils and crops is necessary so that researchers and producers can effectively integrate planting green into soybean-based crop production systems.

Planting green could affect the sensitive indicators of soil health including particulate organic matter, soil organic matter, and aggregate stability (Moore et al., 2014). These soil health indicators are interrelated. For instance, an increase in soil particulate organic matter concentration with planting green can improve soil aggregation, nutrient storage and availability, and soil biological activities, among other processes. Similarly, soil aggregate stability, which is a sensitive soil physical property, influences water infiltration, root growth, microbial activity, aeration, and soil erosion (Amézketa, 1999).

A better understanding of how planting green affects the above soil health parameters and others is needed, as studies on planting green and soils are rare. A 2-year planting green study in Iowa found that a cereal rye CC terminated 6 or 12 days after planting corn increased CC biomass production compared with CC terminated 17 or 3 days before planting corn (Acharya et al., 2022). Cover crop biomass production can gradually increase as the number of days until CC termination increases. The same study by Acharya et al. (2022) found that in both years the no-CC treatment produced the greatest corn yield while the 12-days after planting corn termination treatment produced the lowest yield, suggesting that planting green may contribute to reduced corn yield. Further, previous CC research on soils under typical CC termination timing in Nebraska suggests that CCs may or may not improve soil properties, especially in the short term (<3 years) and when CC biomass production is low (<2 Mg ha^{-1}; Ruis et al., 2017; Sharma et al., 2018; Sindelar et al., 2019). Research also shows that changes in soil properties are often observed only near the soil surface (<10 cm; Sharma et al., 2018).

Core Ideas

- Cover crop (CC) biomass was five times more if terminated 2 weeks after planting soybean than terminated 2 weeks before planting.
- Cover crops reduced soil total nitrogen (N) concentration by 48% but had no effect on other soil properties.
- Cover crop termination timing had inconsistent effects on soybean yield.
- Planting green did not affect most soil properties or soybean yield after 2 years.

Quantifying potential changes in soil properties due to planting green can provide valuable information about planting green as a CC management practice in the Midwest Unites States. Thus, the objectives of this 2-year study were to evaluate the impact of planting green on soil properties (bulk density, wet aggregate stability, sorptivity, particulate organic matter, organic matter, and nutrients) and soybean yield in an irrigated no-till soybean system in south-central Nebraska. Our hypothesis was that planting green would rapidly improve soil properties due to potential greater biomass production relative to early-terminated CCs (typical practice) in the region.

2 | MATERIALS AND METHODS

2.1 | Study location and experimental design

This 2-year study was conducted on an experiment established at the University of Nebraska-Lincoln's South Central Agricultural Lab (SCAL) near Harvard, NE (40.52°N, 98.05°W) in fall 2020. The soil at the experimental site was silt loam (58% silt, 17% sand, 25% clay content) with an organic

TABLE 1 Management of main crop (soybean) and cereal rye cover crop (CC) for the planting green experiment near Harvard, NE, during 2020–2022.

Year	Date	Field operations
2020	October 16	Cover crop drilled at 95.32 kg ha^{-1} with a no-till drill
	December 6	Glyphosate applied to terminate weed in no CC treatments
2021	April 1	Herbicide maintenance applied
	April 24	Cover crop terminated by glyphosate 2 weeks before planting
	April 24	Cover crop biomass collected 2 weeks before planting soybean
	May 12	Dicamba/glyphosate-resistant soybean planted at 330,000 seeds ha^{-1}
	May 26	Cover crop terminated by glyphosate 2 weeks after planting soybean
	May 26	Cover crop biomass collected 2 weeks after planting soybean
	June 14	Soil samples collected at 0- to 5-cm depth, 5- to 10-cm depth, 10- to 20-cm depth
	June 14	Soil sorptivity measured under field conditions
	November 10	Soybean harvested
	November 15	Cover crop drilled at 95.32 kg ha^{-1} with a no-till drill
2022	March 28	Glyphosate applied to terminate weed in no CC treatments
	April 28	Herbicide maintenance applied
	April 28	Cover crop terminated by glyphosate 2 weeks before planting
	April 28	Cover crop biomass collected 2 weeks before planting soybean
	May 18	Dicamba/glyphosate-resistant soybean planted at 330,000 seeds ha^{-1}
	May 31	Cover crop terminated by glyphosate 2 weeks after planting soybean
	May 31	Cover crop biomass collected 2 weeks after planting soybean
	June 14	Soil samples collected at 0- to 5-cm depth, 5- to 10-cm depth, 10- to 20-cm depth
	June 14	Soil sorptivity measured under field conditions
	October 13	Soybean harvested

matter concentration of 3.70% and pH 6.80. The experiment was established after corn harvest in 2020 and was then managed under no-till continuous soybean during the 2-year study with crop residues left on the soil surface postharvest (Table 1). Soybean (the main crop) was sprinkler irrigated, but the CC was never irrigated.

The study experiment was a randomized complete block design with four replications. The treatments were no CC, CC terminated 2 weeks before planting (2WBP) soybean, and CC terminated 2 weeks after planting (2WAP) soybean. Each experimental plot was 3-m wide and 9-m long with four soybean rows spaced 76.2 cm apart. Cereal rye (Elbon Cereal Rye, Green Cover Seed) CC was drilled in fall after crop harvest in both years. Cereal rye was seeded at a rate of 95.32 kg ha^{-1} in 20.32-cm row spacing and to 3.20-cm seeding depth (Table 1). The CC seeding rate was similar to that used in the previous CC studies in the region (Koehler-Cole et al., 2020). Planting occurred during the same week in 2021 and 2022 (Table 1). The staging of cereal rye was conducted using the Zadok's scale (Zadoks et al., 1974). Cereal rye growth stages were taken at the time of biomass collection, and plants were at stage 21–32 when biomass was collected at 2WBP and stage 49–59 when collected at 2WAP. Cover crop were terminated using glyphosate at 1260 g ae ha^{-1} + crop oil concentrate 1% v/v + ammonium sulfate 3% v/v. Glyphosate- and dicamba-resistant soybean was planted at a rate of 330,000 seeds ha^{-1} to a 3.8-cm depth and in 76.20-cm row spacing. Soybean was planted on May 12, 2021 and May 18, 2022 (Table 1). The soybean crop was at the V1-V2 stages in both years when the CC was terminated at 2WAP.

2.2 | Data collection

We measured the following soil properties in this study: soil bulk density; wet aggregate stability; sorptivity (initial water infiltration); pH; and concentrations of particulate organic matter, organic matter, and total C, nitrogen (N), phosphorus (P), and potassium (K). Soil samples were collected 2 weeks after the 2WAP CC termination in the summer of 2021 and 2022. Five intact soil cores (20-cm long) were taken with a 1.90-cm diameter hand probe from each plot and sliced at 0- to 5-cm depth, 5- to 10-cm depth, and 10- to 20-cm depth. Soil samples were composited by depth in each plot, sealed in ziplock bags, transported to the laboratory, and weighed. Next, a fraction of the soil sample was weighed, dried at 105˚C for 24 h, and weighed again to determine gravimetric water content and soil bulk density by the core method (Blake & Hartge, 1986).

Wet aggregate stability was determined using the wet sieving method (Nimmo & Perkins, 2002). Fifty grams of air-dried soil sample passed through 8-mm sieves was placed on top of a column of sieves with openings of 4.75, 2.00, 1.00, 0.50, and 0.25 mm. The top sieve (4.75-mm sieve) contained filter paper to hold the sample for saturation via capillarity for 10 min. The filter paper was then removed, and the soil samples were mechanically sieved for 10 min. The aggregates from each sieve were transferred into pre-weighed beakers, dried at 105˚C for 2 days, and weighed. The amount of dry aggregates and the sieve sizes were used to compute the mean weight diameter of water-stable aggregates (Nimmo & Perkins, 2002).

Another fraction of the air-dried soil sample was gently crushed, passed through 2-mm sieves, and analyzed for chemical properties including total C, organic matter, N, P, and K concentrations, and pH. Total organic C concentration was determined by the dry combustion method on samples milled on a roller mill (Nelson & Sommers, 1996). Soil P concentration was measured by the Mehlich-3 extraction procedure (Frank et al., 2015). One gram of soil sample was mixed with 10 mL of the extracting solution, shaken for 5 min, and transferred to test tubes for the analysis using Lachat QuickChem (Lachat Instruments). K concentration was determined by the ammonium acetate method (Warncke & Brown, 2015). Two grams of soil sample was mixed with 20 mL of 1 N ammonium acetate solution, shaken for 5 min, and filtered for the analysis via inductively coupled plasma (iCAP 6000 series; Thermo Scientific). Soil pH was measured on soil and water slurry in a 1:1 ratio (Peters et al., 2015).

To determine particulate organic matter concentration, 30 g of soil from each sample was dispersed with 5 g L^{-1} sodium hexametaphosphate for at least 24 h and then the mix was washed through 53-µm sieves (Cambardella et al., 2001). The remaining sample on top of the 53-µm sieves was dried at 60˚C until a constant mass was reached. After weighing, the samples were then ashed at 450˚C in a muffle furnace for 4 h. Particulate organic matter concentration was then calculated as the difference between sample mass after drying and ashing. Soil organic matter concentration was analyzed by loss on ignition (Combs & Nathan, 1998). Briefly, 5 g of air-dried soil were oven-dried at 105˚C for 2 h, weighed, heated to 360˚C for another 2 h, and weighed again to compute soil organic matter concentration.

Soil sorptivity was determined using the method outlined by Smith (1999). Three steel rings (9.75-cm diameter by 10-cm height) were inserted into the soil at three locations within each plot and 75 mL of water was added. The time needed to infiltrate the 75 mL of water was recorded to compute sorptivity as per Equation (1):

$$S = \frac{h}{t^{\frac{1}{2}}} \tag{1}$$

where S is sorptivity (cm $s^{-1/2}$), h is the height of water (cm), and s is time (s).

Soybean yield was determined by harvesting the middle two rows of each plot and then adjusting the yield to 13.5% moisture content.

2.3 | Statistical analysis

Statistical analysis of the data was performed using SAS PROC GLIMMIX in SAS 9.4. The data on all soil properties were normally distributed. Year and CC termination treatments were considered as fixed effects, while replication was the random effect in the model. If year × treatment interaction was not significant, data were averaged across both years. When differences in treatments were significant, a multiple comparison test was conducted using Tukey–Kramer's honestly significant difference test with a 95% confidence interval and means were then compared. Also, correlation analysis among soil properties and CC biomass yield was performed using PROC CORR in SAS to determine any relationships among the study variables. Differences in treatment effects were declared significant at $p < 0.05$.

3 | RESULTS AND DISCUSSION

3.1 | Temperature and precipitation

Growing conditions differed between the 2021 and 2022 growing seasons. Sufficient rain and snowfall occurred in fall 2020 and winter 2021, which resulted in adequate CC emergence and growth for 2020–2021 (Table 2). However, below-average rain and snow in fall 2021 and winter 2022 (Table 2) hindered the emergence of the CC; and a viable CC stand was not successful until the spring months of 2022. The highly variable weather conditions from year to year during this experiment appear to reflect the "new normal" weather conditions under the increasing climatic fluctuations in the region and elsewhere (D'Agostino & Schlenker, 2016; Schmitt et al., 2022). Thus, the study results of variable CC biomass production likely capture the variable weather and CC growth conditions in the region.

Soybean was planted within the normal planting time in the region (mid-May) in both years. Soybean was irrigated in both years to compensate for the lower precipitation during the study years compared with the 30-year average (Table 1).

TABLE 2 Mean temperature and precipitation in 2020–2022 for the planting green experimental site near Harvard, NE.

Month	Mean air temperature (°C)				Monthly precipitation (mm)			
	2020	2021	2022	30-year average	2020	2021	2022	30-year average
January	−2.3	−0.9	−3.7	−3.4	22	34	8	15
February	−0.1	−9.6	−2.6	−1.3	3	16	0	21
March	6.1	7.2	4.2	4.6	43	30	36	34
April	9.7	11.2	11.9	10.3	57	13	22	65
May	15.4	15.7	16.2	16.4	52	87	105	136
June	25.3	23.1	22.8	22.6	43	43	56	107
July	25.2	23.3	24.0	24.7	53	51	100	105
August	24.5	23.5	22.7	23.4	15	58	17	98
September	18.4	21.1	21.6	18.9	30	66	41	57
October	10.2	11.8	11.6	11.8	5	17	15	60
November	7.3	6.6	7.2	4.3	42	10	36	35
December	0.0	2.3	1.8	−1.5	16	6	25	25
Average	11.0	11.3	11.50	10.90	381	432	460	756

In 2022, soybean was not irrigated until July 1 due to the installation of a new linear irrigation system. In both years (2021 and 2022), the average temperature was 21°C during the growing season, which is similar to the 30-year average for the site. A weather event to note is a hail and windstorm that occurred on June 7, 2022, when soybean was at the V1-V2 growth stage and adversely impacted soybean stand and growth. As alluded earlier, the extreme events (i.e., hailstorms and windstorms) are not uncommon under the increasing variable climatic conditions. Adaptation and adjustment of crop and CC management practices will be increasingly important under the new climate conditions (Elahi et al., 2022; Schmitt et al., 2022).

3.2 | Cereal rye biomass production

Cover crop termination treatments affected CC biomass production as expected. In 2021, on average, CC-terminated 2WBP accumulated 1.95 Mg ha^{-1} of biomass, while CC-terminated 2WAP accumulated 12.78 Mg ha^{-1} (Figure 1). In 2022, on average, CC-terminated 2WBP accumulated 2.75 Mg ha^{-1} of biomass, while CC-terminated 2WAP accumulated 11.29 Mg ha^{-1} (Figure 1). Averaged across both years, CC produced 2.35 Mg ha^{-1} of biomass for the 2WBP treatment and 12.03 Mg ha^{-1} for the 2WAP treatment (Figure 1).

Cover crop-terminated 2WAP produced more biomass than CC-terminated 2WBP due to the four additional weeks of growth for the 2WAP CC treatment. The 2WBP termination treatment reflects the typical CC termination time in the region. In the study region, temperatures and rainfall can be optimal during April and May (Table 2). Thus, delaying CC termination can lead to rapid growth in CCs such as cereal rye.

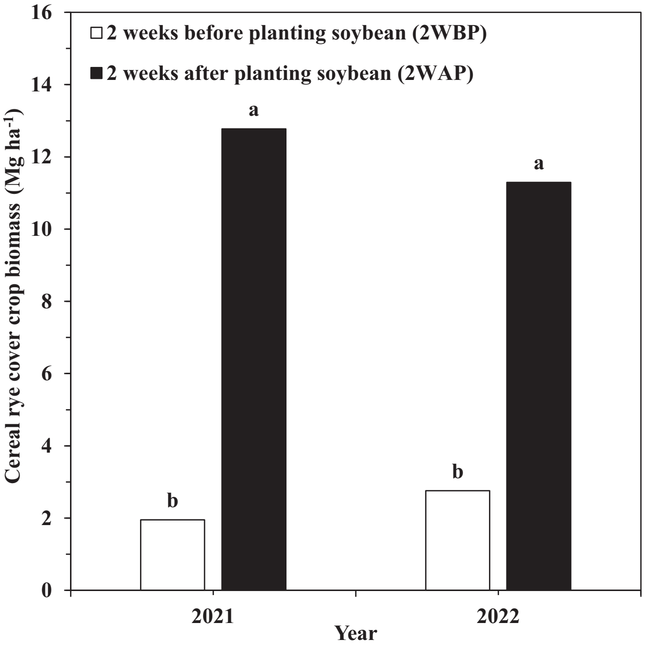

FIGURE 1 The effect of cereal rye cover crop (CC) termination timing on biomass accumulation for the planting green experiment conducted near Harvard, NE, in 2021 and 2022. Means with different lowercase letters within the same year are significantly different.

Note that CC biomass production under the 2WAP treatment rose by about five times (2.35 vs. 12.03 Mg ha^{-1}) relative to the 2WBP treatment. This increase (9.68 Mg ha^{-1}) is much larger than the increase in CC biomass production reported in previous studies on late CC termination (Ruis et al., 2017). For example, a 3-year study in our region found

TABLE 3 Effect of planting green on soil physical properties for the experiment near Harvard, NE, in 2021 and 2022.

	Bulk density (Mg m^{-1})		Mean weight diameter of water-stable aggregates (mm)		Sorptivity (cm s^{-1})	
Treatment	2021	2022	2021	2022	2021	2022
No cover crop	1.13a	1.13a	1.01a	0.68a	0.12a	0.10a
2WBP	1.09a	1.08a	1.40a	0.84a	0.11a	0.08a
2WAP	1.12a	1.10a	1.49a	1.07a	0.12a	0.10a

Note: Means with common letter within each column are not significantly different at the 0.05 probability level.
Abbreviations: 2WAP, 2 weeks after planting; 2WBP, 2 weeks before planting.

that late-terminated cereal rye CC (at corn planting) produced only 0.85 Mg ha^{-1} (1.60 vs. 0.75 Mg ha^{-1}) more biomass than CC terminated 2–3 weeks before corn planting (Ruis et al., 2017). The CC in our study produced more biomass than the late-terminated CC in the study by Ruis et al. (2017) because it was terminated 2 weeks later (2WAP). Thus, our results suggest that planting green can be a strategy to further boost CC biomass production. However, how the increased CC biomass production affects soils and crop yields deserves discussion.

3.3 | Soil physical properties

Cereal rye CC termination treatments (no CC, 2WBP, and 2WAP) had no effect on soil bulk density ($p = 0.76$), wet aggregate stability ($p = 0.21$), or sorptivity ($p = 0.20$) in any year (Table 3). However, the year had an effect on wet aggregate stability ($p = 0.0003$) and sorptivity ($p = 0.0003$) but not on bulk density. Results indicate that the year affected soil physical properties more than CC termination treatment. Both wet aggregate stability and sorptivity decreased from 2021 to 2022 in all treatments. The year-to-year fluctuation in dynamic soil properties such as wet aggregate stability and sorptivity is not uncommon, especially in temperate regions. Differences in freezing-thawing and wetting-drying from year to year can differently impact soil properties near the soil surface (Dagesse, 2011).

The lack of significant impacts of CC termination timing on bulk density agrees with the few previous studies, which found that CCs generally have small effects on soil bulk density in temperate regions (Hubbard et al., 2013; Villamil et al., 2006). Cover crops often alter soil bulk density in the long term (>10 years) if CC biomass production is high (Blanco-Canqui et al., 2011). While CC termination timing on soil bulk density was not significant, the numerical values of bulk density slightly decreased (from 1.13 to 1.09 Mg m^{-3}) under CCs. The decreasing trend in bulk density suggests that bulk density in the study soil may decrease with the continued use of planting green in the long term. A decrease in bulk density can increase soil porosity and reduce risks of compaction relative to fields without planting green.

Similarly, although not statistically significant, wet aggregate stability increased with both 2WBP and 2WAP treatments compared with no CC in both years (Table 3). The increasing trend in wet aggregate stability was larger with 2WAP than with 2WBP treatment. Thus, similar to soil bulk density, the tendency for improved aggregate stability after 2 years suggests that this property can improve under planting green in the long term. Cover crops can increase wet aggregate stability, especially in the long term (>10 years; Blanco-Canqui et al., 2011; Steele et al., 2012).

Further, the correlation analysis showed that wet aggregate stability was the only soil property impacted ($p = 0.067$) by CC biomass production (Figure 2a). Across both years, wet aggregate stability increased as the amount of CC biomass increased (Figure 2a). This significant correlation suggests that CCs could maintain or improve soil aggregate stability probably due to their abundant canopy cover, which slows and intercepts raindrops, thereby reducing their erosive energy (Ruis et al., 2020; Wassenaar et al., 2005). The correlation analysis also showed that sorptivity which is the initial water infiltration, increased as wet aggregate stability increased ($p = 0.0037$; Figure 2b). While CC termination timing did not affect sorptivity in the short term (2 years), the positive correlation between sorptivity and aggregate stability suggests that planting green could increase sorptivity in the long term if CCs significantly increase wet aggregate stability, which promotes macroporosity. Previous studies in the region also found that CCs may have limited effects on soil sorptivity in the short term (<4 years) even when CCs produce large amounts of biomass (about 4 Mg ha^{-1}; Ruis et al., 2020).

In this study, CC produced as high as 12.78 Mg biomass ha^{-1} under planting green (2WAP) but did not affect soil physical properties after 2 years. One reason for the limited effect of planting green on the soils in this study may be the initial soil conditions. The study site had been managed under no-till for decades before the CC study initiation. Thus, because soil properties may have already been improved, it could take more than 2 years for planting green to induce further changes in soil properties in this and similar soils. For example, bulk density ranged from 1.08 to 1.13 Mg m^{-3}, which was near optimum for highly productive silt loam soils in no-till. Also,

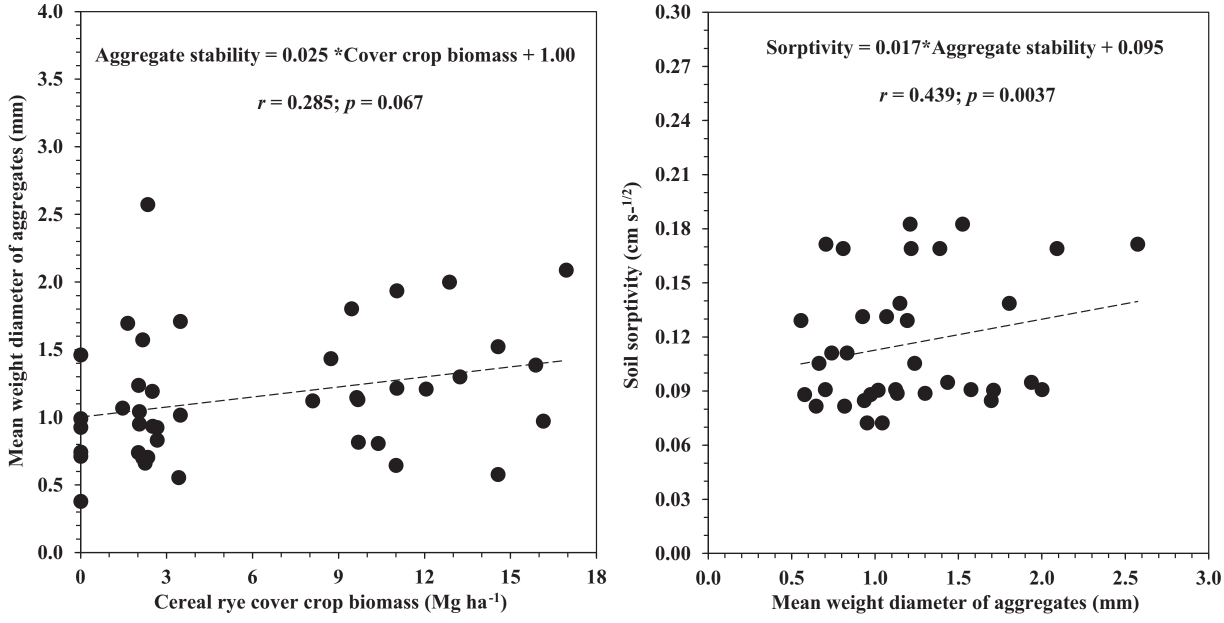

FIGURE 2 Relationship of wet aggregate stability expressed as mean weight diameter of aggregates with (a) cereal rye biomass production and (b) soil sorptivity across 2 years for the planting green experiment conducted near Harvard, NE, in 2021 and 2022.

the initial organic matter (3.7%) in the study soil was higher than for most agricultural soils. Most croplands have organic matter concentration below 3% on a global scale (Oldfield et al., 2019; Yang et al., 2017). Plowed or degraded soils with less than ideal soil properties may respond more rapidly to planting green than soils under long-term no-till management (Olson et al., 2014).

However, in the long term (>3 years) even in no-till soils with relatively high organic matter concentration, high biomass input from CCs on an annual basis can exert significant changes in soils and crop yields, as reported by some studies in the region (Blanco-Canqui et al., 2023; Ruis et al., 2023). Thus, we hypothesize that, under the conditions of this experiment, continued CC biomass input at rates above 10 Mg biomass ha^{-1} under planting green would significantly alter soil health indicators and crop production in the long term (>3 years).

3.4 | Soil chemical properties

Similar to the impacts on soil physical properties, CC treatments had no impact on soil chemical properties ($p > 0.05$) except for total N ($p < 0.05$; Table 4). The year × CC termination interaction was significant for total N. In 2021, both 2WBP and 2WAP treatments reduced total N concentration by 48% (31.10 vs. 59.70 mg kg^{-1}) but not in 2022 (Table 4). Data on pH, particulate organic matter, organic matter, and total C, P, and K were averaged across both years as year × CC interaction was not significant for these properties (Table 4).

Total particulate organic matter tended to increase with both CC termination treatments compared with no CC (Table 4). While the correlation between particulate organic matter and wet aggregate stability was not significant ($p > 0.05$) after 2 years, the increased trend in particulate organic matter under planting green suggests that its positive influence on soil aggregation may develop over the long term. The role of particulate organic matter in binding soil particles and promoting soil aggregation is well recognized (Cambardella et al., 2001). Previous CC studies showed that labile organic matter (i.e., particulate organic matter, water-extractable organic matter) often increases 3 or more years after CC introduction (Ruis et al., 2020).

The lack of CC termination treatment effect on particulate organic matter, soil organic matter concentration, and soil C in this study could be due to the already high organic matter levels in the study soil mentioned earlier. Other studies observed that organic matter concentration can increase only 3 or 5 years after CC adoption (Dabney et al., 2001; Olson et al., 2014; Sainju et al., 2002). The reduction in total N concentration with CCs in one of the 2 years can have important connotations for N management. It suggests that the practice of planting green can reduce nitrate leaching and potentially contribute to N-use efficiency (O'Reilly et al., 2012). One potential reason for increases in total N is that crops tend to use less N in drier years, and both of these years were drier than the 30-year average (Table 2). Another potential reason is that soybean residues can put N credits back into the soil (Dabney et al., 2001; O'Reilly et al., 2012). These two reasons combined could have led to higher N values. Long-term monitoring of planting green impacts on nitrate leaching and other

TABLE 4 Effect of planting green on soil chemical properties and soybean yield for the experiment near Harvard, NE, in 2021 and 2022.

Treatment	Total N (mg kg^{-1})		Particulate organic matter (mg g^{-1})	Total C (g kg^{-1}b	Organic matter (g kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	Soybean yield (Mg ha^{-1})	
	2021	2022						2021	2022
No CC	59.67a	78.67a	9.70a	20.46a	40.17a	123a	478a	4.87a	2.11a
2WBP	33.89b	64.56a	9.87a	20.07a	40.10a	91.30a	451a	3.92a	0.96b
2WAP	28.30b	75.78a	10.60a	19.58a	30.98a	104.56a	470a	3.77a	2.70a

Note: Means with common letter within each column are not significantly different at the 0.05 probability level. The year × treatment interaction was significant only for total nitrogen (N).
Abbreviations: 2WAP, 2 weeks after planting; 2WBP, 2 weeks before planting; C, carbon; CC, cover crop; N, nitrogen; K, potassium; P, phosphorus.

soil processes is needed to better evaluate the effect of planting green on nitrate leaching, soil C, and other soil chemical and fertility properties.

3.5 | Soybean yield

Cover crop termination and year had a significant effect ($p < 0.05$) on soybean yield. Also, the CC termination × year interaction was significant ($p = 0.001$), indicating that CC effect depended on the year. Table 4 shows that soybean yield in 2021 was about 2.20 times higher than in 2022. The yield decrease in 2022 was due to a hail and windstorm that occurred in early June 2022 at the V1-V2 soybean growth stage. Cover crop termination treatments had no effect on soybean yield in 2021, but the 2WBP treatment reduced yield in 2022. The adverse impact of CC (2WBP treatment) on soybean yield in 2022 should be interpreted with caution due to the compounding effect of the hail and windstorms, which reduced soybean stand and growth in all CC treatments. The large fluctuation in soybean yield from year to year due to unexpected weather events strongly suggests the need for long-term studies to better assess planting green effects on crop yields.

In 2021, while differences in soybean yield among CC treatments were not statistically significant, soybean yield ascended in this order: No > 2WBP > 2WAP. This trend suggests that CCs, particularly planting green (2WAP), could reduce crop yields, warranting the need to monitor the crop yield impacts of planting green for multiple years. Indeed, in 2021, visual differences of soybean yellowing and stunting were observed in the 2WAP treatment. Cover crops under 2WAP most likely depleted moisture and immobilized nutrients. Other studies also found that high biomass accumulation for non-legume CCs could reduce crop yields in some cases (Acharya et al., 2022; Ficks et al., 2023; Wallace et al., 2021). A recent field-scale analysis across the US Corn Belt reported that CCs can reduce soybean yield by 3.5% in years with low precipitation and warm temperatures in spring (Deines et al., 2023). However, results indicate that in 2022, the year with abnormal weather, planting green (2WAP) tended to increase soybean yield relative to 2WBP and no CC treatments (Table 4). The abundant CC biomass in the 2WAP treatment may have protected the soybean stand from the hail and windstorm, leading to better soybean stand.

One may expect that an improvement in soil properties such as soil organic matter concentration could translate into increased crop yields, particularly in soils with relatively low initial organic matter. For example, Oldfield et al. (2019) discussed that soil productivity increases as soil organic matter concentration increases, although it can plateau as organic matter concentration reaches 3.4%. However, in this study, CCs had no effect on most soil properties, including organic matter concentration, in the short term. Thus, the need for a long-term planting green study cannot be overemphasized for determining definitive conclusions about the effects of planting green on soils and crop production.

4 | CONCLUSIONS

Our research on planting green conducted under an irrigated no-till soybean system in the western US Corn Belt for 2 years generated initial findings about the potential implications of early (2WBP soybean) and late (2WAP soybean) cereal rye CC termination on soil properties and soybean yield. Results show that the abundant amount (12 Mg ha^{-1}) of CC biomass that was produced under planting green had limited or no significant effect on most soil properties in the short term. Our hypothesis that planting green would rapidly improve soil properties due to high biomass accumulation relative to lower amounts of biomass produced under typical CC management practices in the region was not supported by the data.

In addition, results show that planting green does not reduce soybean yields, yet planting green contributed to nitrate scavenging, particularly in the first year. Further, the significant positive correlation between wet soil aggregate stability and CC biomass production can be early indicators of the soil benefits of planting green. In general, the limited or no impacts of planting green on soil properties and soybean yield in the short term suggest the need for long-term future research on planting green to improve soil properties while reducing negative impacts on crop yields.

AUTHOR CONTRIBUTIONS

Trey Stephens: Data curation; formal analysis; investigation; methodology; project administration; writing—original draft. **Humberto Blanco-Canqui**: Supervision; validation; writing—review and editing. **Stevan Z. Knezevic**: Supervision; validation; writing—review and editing. **Jennifer Rees**: Supervision; validation; writing—review and editing. **Katja Koehler-Cole**: Supervision; validation; writing—review and editing. **Amit J. Jhala**: Conceptualization; formal analysis; funding acquisition; investigation; methodology; project administration; resources; software; supervision; validation; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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