Progress report 3 – February 28, 2023 MSRPC Project: 10-15-48-22018

FARMER-DRIVEN RESEARCH INTO PLANTING GREEN ALONG THE RED

Institution/Organization: Regents of the University of Minnesota

Principal investigator: Angie Peltier, apeltier@umn.edu, 218-281-8692 (o) 414-704-1931 (c)

Co-PIs: Jodi DeJong Hughes, UMN Extension; Anna Cates, UMN Extension & Minnesota Office for Soil Health; Lindsay Pease, UMN Extension & Northwest Research & Outreach Center.

Cooperators: Dorian Gatchell, Minnesota Agricultural Services; Melissa Carlson and Chris Matter, On-Farm Research Network, Minnesota Wheat Research & Promotion Council.

On-farm experimental Design:

Treatments were arranged as large strips wide enough to accommodate farmers' equipment in a randomized complete block design with three replications. Nutrient cycling, soil health, rye biomass at termination, soybean stand count, yield, moisture & test weight data were collected from each plot.

Treatments: 1) Current tillage practice without a fall-seeded cereal rye cover crop (CC),
2) CC terminated 1-2 weeks before soybean planting,
3) CC terminated at soybean planting,
4) CC terminated 1-2 weeks after soybean planting.

Purpose of Study:

Minnesota (MN) farmers face difficult choices when deciding to prioritize either long-term soil health goals or the immediate benefits of tillage for residue management and seedbed preparation. Despite the reported soil health benefits of cover crops, a short growing season makes delays to spring field work risky. Research on cover cropping suggests that early season cover crops can stabilize yields by mitigating excess and limited soil moisture, improving field trafficability, and reducing wind erosion. Reliable advice on agronomic outcomes of cover cropping is critically needed by MN farmers interested in adopting reduced-tillage and cover cropping systems. To meet this need, we partnered with MN farmers to design 5 replicated, production-scale research and demonstration trials that were sown to cereal rye in *Fall 2021* (**Figure 1, Table 1**). Soybeans were seeded in spring 2022 and cover crops terminated before, at or after soybean planting.

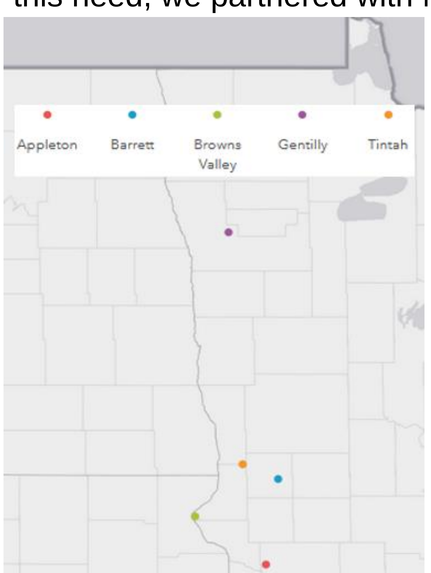

Figure 1. On-farm trial locations in 2021-2022.

Table 1. Dates that the 2021 winter rye cover and 2022 soybean crop were seeded and soybean seeding rate in five Minnesota farm fields

Town	Rye seeded (2021)	Soybean seeded (2022)	Soybean seeding rate (per acre)
Appleton	Oct 30-31	May 10	140,000
Browns Valley	Oct 31	May 23	165,000
Tintah	Sep 8	Jun 8	140,000
Barrett	Oct 31	May 27	165,000
Gentilly	Sep 7	Jun 7	175,000

Each trial location grew different soybean varieties and had different soybean seeding dates and rates and therefore different dates of rye termination and so results are presented by location.

Browns Valley. The before-planting and no-rye plots had similar biomass, the at-planting treatment accumulated 1,811 lb/A more biomass and after-planting still an additional 1,585 lb/A (**Table 2**).
There was a numerical trend with the lower the rye biomass the greater the soybean stand count. The after-planting rye termination averaged 21,511 fewer plants/A than the other treatments.
Soybean yields were similar for all but the lower yielding after-planting rye termination timing. Soybean moisture and test weights were similar among treatments.

Table 2. The effect of rye termination timing on rye biomass, soybean stand count, yield, moisture and test weight at the Browns Valley, MN farm

Rye termination timing	Rye biomass (lb/A)	Soybean stand count (plants/A)	Yield (bu/A)	Moisture (%)	Test weight (lb/bu)
Before planting	1280 a[z]	104,221 b	41.7 b	11.6	57.7
At planting	3091 b	103,576 b	41.2 b	11.6	57.7
After planting	4676 c	83,248 a	34.5 a	11.6	47.3
No rye	N/A	106,480 b	39.4 b	11.7	57.20
LSD (90% CL)	44	10,492	2.61	NS	NS
CV (%)	14.66	6.65	4.19	0.81	15.76

[z] Treatment means within a column that are followed by different letters are significantly different at *P* = 0.10.

Tintah. Termination timing had a significant effect on rye biomass, with greater biomass accummulation occurring with each successive timing (**Table 3**). The no-rye and before-planting termination timing treatments had significantly higher soybean stand counts than the plots in which rye was terminated at or after soybean planting.
The soybean yields in the no-rye and before-planting termination timing plots were similar and greater than in plots in which rye was terminated at planting. Yield was lowest when rye termination took

place after soybean planting. Oddly, soybean test weights were significantly lower in plots with no rye or when rye was terminated before planting than when rye was terminated at planting.

Table 3. The effect of rye termination timing on rye biomass, soybean stand count, yield, moisture and test weight at the farm in Tintah, MN

Rye termination timing	Rye biomass (lb/A)	Soybean stand count (plants/A)	Yield (bu/A)	Moisture (%)	Test weight (lb/bu)
Before planting	1370 a[z]	111,320 b	44.4 c	10.8	58.4 a
At planting	3413 b	95,040 a	40.0 b	10.7	59.3 b
After planting	4470 c	87,560 a	36.5 a	10.9	59.0 ab
No rye	N/A	109,120 b	45.6 c	10.8	58.3 a
LSD (90% CL)	957	11,257	1.60	NS	0.71
CV (%)	38.30	7.04	2.42	0.99	0.70

[z] Treatment means within a column that are followed by different letters are significantly different at *P* = 0.10.

Barrett. Rye biomass was significantly lower when terminated before soybean planting, than when terminated either at or after soybean planting (**Table 4**). The soybean stand did not differ among treatments.

Soybean yield was statistically similar regardless of rye termination timing, and lower than when grown without the rye cover crop. Soybean moisture was lowest in plots in which rye was terminated after soybean planting and highest in plots without rye or when rye was terminated before soybean planting.

Table 4. The effect of rye termination timing on rye biomass, soybean stand count, yield, moisture and test weight at the farm near Barrett, MN

Rye termination timing	Rye biomass (lb/A)	Soybean stand count (plants/A)	Yield (bu/A)	Moisture (%)	Test weight (lb/bu)
Before planting	1128 a[z]	130,357	45.9 a	10.8 b	57.3
At planting	2211 b	128,421	46.9 a	10.7 ab	57.2
After planting	2664 b	139,392	45.3 a	10.6 a	56.7
No rye	N/A	147,781	54.9 b	10.8 b	56.8
LSD (90% CL)	585	NS	3.1	0.2	NS
CV (%)	36.35	9.35	4.5	1.27	0.64

[z] Treatment means within a column that are followed by different letters are significantly different at *P* = 0.10.

Gentilly. Each successive rye termination timing allowed for significantly more biomass to accumulate when compared to the previous timing (**Table 5**). Rye biomass was perhaps responsible for the lower soybean stand count the greater the biomass accumulation, and significantly lower stands in the plots in which rye was terminated at or after soybean planting.

Surprisingly, soybean yields were statistically similar and greater in the plots with no-rye, at-planting and after-planting rye termination treatments than in the plots in which rye was terminated before planting. Soybean moisture content was significantly similar and higher in the rye plots than in the no-rye plots. Soybean test weight was significantly higher in the plots in which rye was terminated after-planting than at-planting.

Table 5. The effect of rye termination timing on rye biomass, soybean stand count, yield, moisture and test weight at a farm near Gentilly, MN

Rye termination timing	Rye biomass (lb/A)	Soybean stand count (plants/A)	Yield (bu/A)	Moisture (%)	Test weight (lb/bu)
Before planting	2061 a[z]	196,698 ab	35.7 a	12.2 b	60.7 ab
At planting	4384 b	175,015 a	41.4 b	12.5 b	60.2 a
After planting	4965 b	168,045 a	40.9 b	12.5 b	60.9 b
No rye	N/A	215,283 b	44.2 b	11.5 a	60.8 ab
LSD (90% CL)	1165	29,186	4.9	0.6	0.7
CV (%)	37.53	9.75	7.63	2.85	0.77

[z] Treatment means within a column that are followed by different letters are significantly different at *P* = 0.10.

Appleton. The first rye termination at the Appleton farm took place at soybean planting. A significant additional 238 lb/A of rye biomass were added in the 13 days between soybean planting and the after-planting termination timing (**Table 6**).

A numerical trend was observed in that the greater the cover crop biomass, the lower the soybean stand count. However, this slight trend did not result in any statistical differences among treatments for soybean yield, moisture and test weight.

Table 6. The effect of rye termination timing on rye biomass, soybean stand count, yield, moisture and test weight at a farm near Appleton, MN

Rye termination timing	Rye biomass (lb/A)	Soybean stand count (plants/A)	Yield (bu/A)	Moisture (%)	Test weight (lb/bu)
Before planting	Treatment not included at this location				
At planting	146 a[z]	115,837	39.9	10.9	56.2
After planting	384 b	114,869	36.8	10.5	56.9
No rye		116,483	46.4	10.0	55.9

LSD (90% CL)	1.6	NS	NS	NS	NS
CV (%)	10.34	1.70	10.64	8.13	1.74

[z] Treatment means within a column that are followed by different letters are significantly different at *P* = 0.10.

On-farm summary. This document summarizes crops grown in farmer cooperators' fields in two abnormal growing seasons. The rye cover crop was seeded after an abnormally early harvest of the 2021 wheat crop (Gentilly) due to exceptional drought conditions or into standing corn crops (Barrett, Browns Valley, Tintah, Appleton) and then in spring 2022, soybean was seeded a month (or greater) later than normal due to very wet soil conditions, allowing for considerable rye growth before planting. Only time will reveal how 'typical' the results of this 2021-22 study were.

<u>Rye biomass & soybean stand count.</u> Delaying cover crop termination until 1-2 weeks after soybean planting produced more cover crop biomass; at four of the five trial locations, there was significantly more biomass with this delayed termination. However, at most of the locations, planting soybean into a living cover crop that was then terminated either immediately after planting or two weeks later resulted in numerically lower soybean stand counts when compared soybeans grown in plots in which the rye was terminated before planting or in plots without rye. In most locations, there was no yield decrease when the rye biomass was only allowed to accumulate to between 2,000 and 3,500 lb/acre.

<u>Soybean yield, moisture & test weight.</u> At one location, there were no differences in yield among cover crops treatments; at another, all of the treatment yields were similar with the surprising exception of lower yield in plots terminated before soybean planting. At two locations, regardless of termination timing, rye plots yielded significantly less than the no-rye plots. In another location, yield in the no-rye plots was statistically similar to yield in rye plots terminated before soybean planting, with each later termination timing yielding significantly less than plots of earlier termination timing. Soybean moisture and test weight were not affected by cover crops treatments at three of the five trial locations. At one location, soybean moisture was higher when a cover crop was grown than when not; at another, soybean moisture was lower in rye plots that were terminated after planting than in the no rye or other rye termination timings. At one location test weight was higher and at another lower when rye was terminated at planting.

University of Minnesota Research & Outreach Centers small plot experimental design:
Treatments were arranged in a split-split plot design with whole plots being tillage, split plots termination timing and split-split plots rye seeding rate treatments. Plots were established in fall 2021 at the Northwest Research & Outreach Center in Crookston, MN after a spring wheat crop. Plots were established in fall 2021 at the West Central Research & Outreach Center in Morris, MN after a corn crop. Nutrient cycling, soil health, rye biomass at termination, soybean stand count, yield, moisture & test weight data were collected from each plot. Treatments are listed below.

Tillage treatments:

1) fall chisel plow followed by spring field cultivation
2) no-till

Rye seeding rate treatments:
1) 0 lb/A
2) 20 lb/A
3) 40 lb/A

Termination timing treatments:
1) No fall-seeded cereal rye cover crop (CC),
2) CC terminated 1-2 weeks prior to soybean planting
3) CC terminated at soybean planting
4) CC terminated 1-2 weeks after soybean planting

UMN Northwest Research & Outreach Center (NWROC), Crookston, MN.

Rye biomass. Between 949 and 2,324 lb/a of rye were present at the time of termination, with significantly more biomass occurring in plots that had received fall and spring tillage than in plots in which rye was planted no-till (**Table 7**). Significantly greater rye biomass grew in plots seeded to 40 lb/A rye than those seeded to 20 lb rye. While the before planting and at soybean planting rye termination timings accumulated statistically similar rye biomass at the time of termination, letting rye grow for an additional 10 days after planting resulted in a near doubling (an additional 1,141 lb of rye per acre) of the biomass accumulated at soybean planting.

There was an interaction between rye termination timing and seeding rate. Unsurprisingly, all of the plots seeded to rye had significantly higher biomass than the plots not seeded to rye and rye accummulation differed among termination timings (**Figure 2**). When terminated either before or after soybean planting, plots planted to 40 lb/A rye in fall 2021 accumulated significantly more rye biomass than plots planted to 20 lb/A rye; there was no difference in rye biomass accumulation between the 20 and 40 lb/A rye seeding rate when terminated at soybean planting.

Soybean stand count. While soybean stand count differed numerically among rye seeding rates, there were no statistical differences among rye seeding rate due to plot to plot variability (**Table 7**). There were however differences between plots chisel plowed in fall 2021 and field cultivated in spring 2022 and no-till plots, with significantly higher soybean stand counts in no-till plots. Some crusting compaction was evident in tilled plots after soybean planting. Crusting can delay or impede soybean seedlings from emerging which may have 'tipped the balance' away from soybean seedlings and toward seed and seedling disease-causing organisms that tend to take advantage of seeds and seedlings remaining below-ground. Lastly, soybean stand count tended to be higher the longer that rye termination was delayed, with the highest stand count in those plots terminated 10 days after soybean planting. In what was a historically wet spring, a rye cover crop not only didn't negatively impact soybean stand, it may have dried the soil out enough to tip the balance toward soybean seedling growth and development and away from seed and seedling pathogens.

Soybean test weight. Soybean test weight for all treatments was lower than 60 lb/bushel, but all test weights would have made U.S. No. 1 grade. No significant differences were observed among rye seeding rate or termination timings. Test weight was significantly higher in no-till plots than in tilled plots (**Table 7**); the higher stand counts in the no-till plots may have assisted soybean plants in combating soil crusting and iron deficiency chlorosis, leading to a slightly higher test weight.

Soybean moisture. No statistically significant differences in soybean moisture were detected among rye termination timing treatments or between different tillage treatments (**Table 7**). However, there were differences in soybean moisture among rye seeding rate treatments with the 40 lb/A rye seeding rate plots resulting in the lowest moisture content and the no-rye plots resulting in the highest moisture content; the 20 lb/A rye seeding rate did not differ from either the 0 or 40 lb/A rye seeding rate. One can speculate that the plots seeded to more rye may have had less soil moisture and those seeded to no rye having more with differences following the crop through to harvest-time soybean moisture values.

Yield. There were no differences among rye seeding rate, tillage or rye termination timing treatments on soybean yield (**Table 7**), nor were there interactions among different treatment combinations.

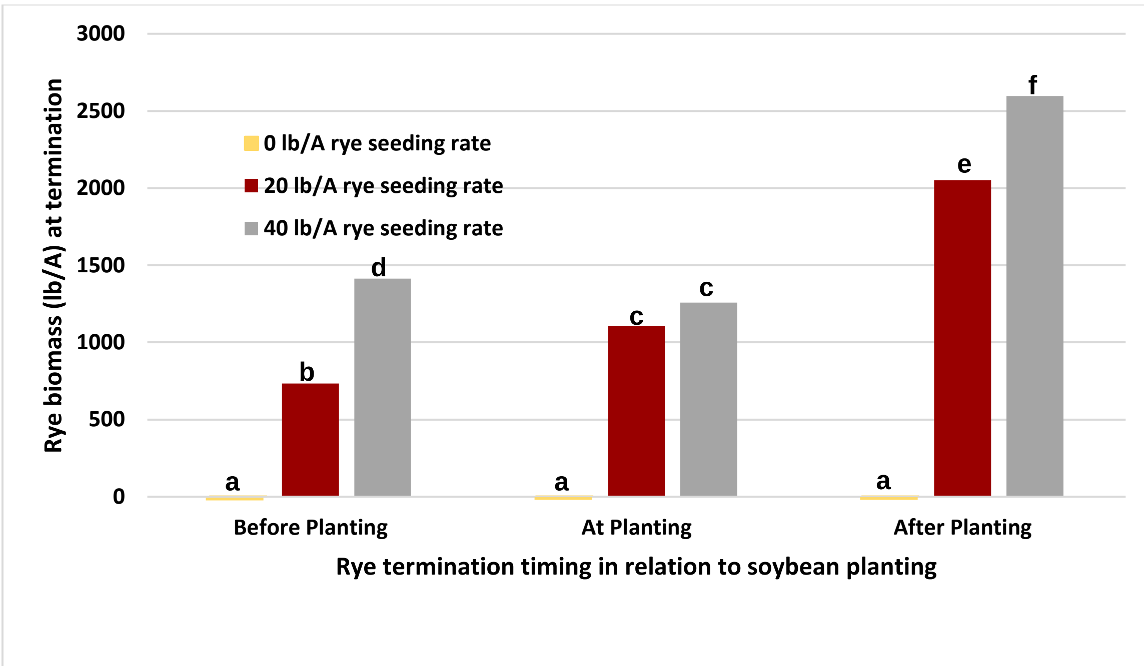

Figure 2. Rye biomass accummulation at termination timing in plots seeded to rye in fall 2021 at 0, 20 and 40 lb/A {*P* = 0.0550, LSD (0.10) = 247 lb/A}; those treatment bars above which sit different letters are significantly different from one another at *P* = 0.10.

Table 7. The effect of rye termination timing on rye biomass, soybean stand count, yield, moisture and test weight at the UMN Northwest Research & Outreach Center near Crookston, MN

Rye termination timing	Rye biomass (lb/A)	Soybean stand count (plants/A)	Yield (bu/A)	Moisture (%)	Test weight (lb/bu)
Before planting	1,074 b*	135,672 a	38.7 a	13.4 a	59.1 a
At planting	1,183 b	144,279 b	37.7 a	13.3 a	59.1 a
After planting	2,324 c	146,997 c	36.3 a	13.3 a	59.2 a
No rye	0 a	135,295 a	34.7 a	13.6 a	58.9 a

Seeding rate (lb/A)	Rye biomass (lb/A)	Soybean stand count (plants/A)	Yield (bu/A)	Moisture (%)	Test weight (lb/bu)
0	0 a	135,295 a	34.7 a	13.6 b	58.9 a
20	1,297 a	140,579 a	36.8 a	13.5 ab	59.2 a
40	1,756 b	144,052 a	38.3 a	13.2 a	59.1 a
Tillage	**Rye biomass (lb/A)**	**Soybean stand count (plants/A)**	**Yield (bu/A)**	**Moisture (%)**	**Test weight (lb/bu)**
Yes	1,086 b	131,771 a	37.2 a	13.5 a	58.9 a
No	949 a	148,180 b	30.0 a	13.4 a	59.2 b
CV (%)	30.69	9.73	20.29	2.11	0.99

* Under each red heading within a column, treatments were significantly different from one another at *P* = 0.10 if the values are followed by different letters.

UMN West-Central Research & Outreach Center (WCROC), Morris, MN.

Rye biomass. Biomass varied among treatment variables, ranging from 0 lbs of rye per acre in the plots not seeded to rye in fall 2021 to 7,365 lbs of rye per acre in plots in which the rye was allowed to grow for an additional 9 days after soybean planting until it was terminated. Rye biomass differed significantly among termination times, with the before soybean planting timing having significantly less rye accummulation than either the at or after soybean planting termination timing (**Table 8**). While there was numerically more rye in the terminated after-soybean planting, these treatments were statistically similar to one another. Rye biomass did not statistically differ among rye planting rate or tillage treatments.

Soybean stand count. While soybean stand counts did not differ among rye seeding rate or tillage treatments, there were significant differences among rye termination timing treatments (**Table 8**). Soybean stands in plots with no rye and in plots in which the rye cover crop was terminated 15 days prior to soybean planting were statistically similar and higher than the stands in plots in which the rye was terminated at or 9 days after soybean planting; the at and after planting termination plots were statistically similar to one another. In a very wet spring (like 2022) in which considerable rye biomass can accumulate before fields are fit to plant, soybean stand count can be nearly halved by delaying termination until at or after soybean planting. This points to the utility of having a ‘back up plan’ for cover crop termination in the case that one were unable to use their full-sized sprayer.

Soybean test weight. Test weights of rye termination timing, tillage and rye seeding rate treatments did not differ from one another within each category of variable (**Table 8**). However, there was a significant ($P = 0.0052$) interaction among termination timing and tillage treatments (**Figure 3**). Soybean test weight was statistically similar in tillage and no-tillage plots that either did not have a rye cover crop or in which the rye cover crop was terminated prior to soybean planting. However, significant differences were observed between tillage and no-till treatments in plots in which the rye cover crop was terminated either at the time of soybean planting or 9 days after soybean planting, but in opposite ways. Test weight was significantly higher in no-till than in tilled plots in which rye was terminated at soybean planting; test weight was significantly higher in tilled than in no-till plots in which rye was terminated after soybean planting. While these were significant differences varying in moisture by between 1 ¼ and 2 ¼ percentage points, treatment test weights were less than or equal to 56.0 %. Only no-till plots in which rye was terminated before soybean planting could be considered to be of U.S. No. 1 grade, all other tillage x termination timing treatment combinations would be considered to be of U.S. No. 2 grade except no-till plots in which rye was terminated after soybean planting which was of U.S. No. 3 grade.

Soybean moisture. Grain moisture of rye termination timing, tillage and rye seeding rate treatments did not differ from one another, nor were there interactions among them (**Table 8**).

Yield. Soybean yields did not differ among the different tillage treatments, different rye seeding rates or different rye termination timings. However, there was a significant rye seeding rate by tillage interaction (P = 0.0846), with most treatment combinations statistically similar to one another (**Figure 4**). Only the tilled plots that were seeded to 0 and 40 lb of rye differed from one another, with no-rye plots out-yielding plots seeded to 40 lb of rye by 14.9 bushels. The year of the trial, 2022, was a year in which planting was delayed by one month and so rye (which was to be terminated at timings in relation to soybean planting) grew for a month longer than in a typical growing year, leading to an odd balance between having . No-till and tillage plots in which rye had not been seeded in 2021 were statistically similar to one another, differing by less than a bushel, but while statistically similar to one another, no-till and tillage plots planted to 40 lb of rye in 2021, differed by 3.6 bu. The reason for these results is still being debated at this time.

Table 8. The effect of rye termination timing on rye biomass, soybean stand count, yield, moisture and test weight at the UMN West Central Research & Outreach Center near Morris, MN

Rye termination timing	Rye biomass (lb/A)	Soybean stand count (plants/A)	Yield (bu/A)	Moisture (%)	Test weight (lb/bu)
Before planting	3,975 b*	113,135 b	40.2 a	9.7 a	55.8 a
At planting	6,462 c	61,226 a	39.1 a	9.7 a	55.2 a
After planting	7,365 c	62,315 a	34.3 a	9.9 a	54.8 a
No rye	0 a	112,207 b	48.4 a	9.7 a	55.4 a
Seeding rate (lb/A)	**Rye biomass (lb/A)**	**Soybean stand count (plants/A)**	**Yield (bu/A)**	**Moisture (%)**	**Test weight (lb/bu)**
0	0 a	112,207 a	48.4 a	9.7 a	55.4 a
20	6,072 a	76,391 a	39.9 a	9.7 a	55.4 a
40	5,796 a	81,393 a	35.9 a	9.8 a	55.2 a
Tillage	**Rye biomass (lb/A)**	**Soybean stand count (plants/A)**	**Yield (bu/A)**	**Moisture (%)**	**Test weight (lb/bu)**
Yes	3,800 a	89,970 a	42.5 a	9.7 a	55.4 a
No	4,112 a	90,024 a	40.2 a	9.8 a	55.1 a
CV (%)	38.29	21.97	30.77	4.06	2.71

* Under each red heading within a column, treatments significantly differed from one another if the values are followed by different letters.

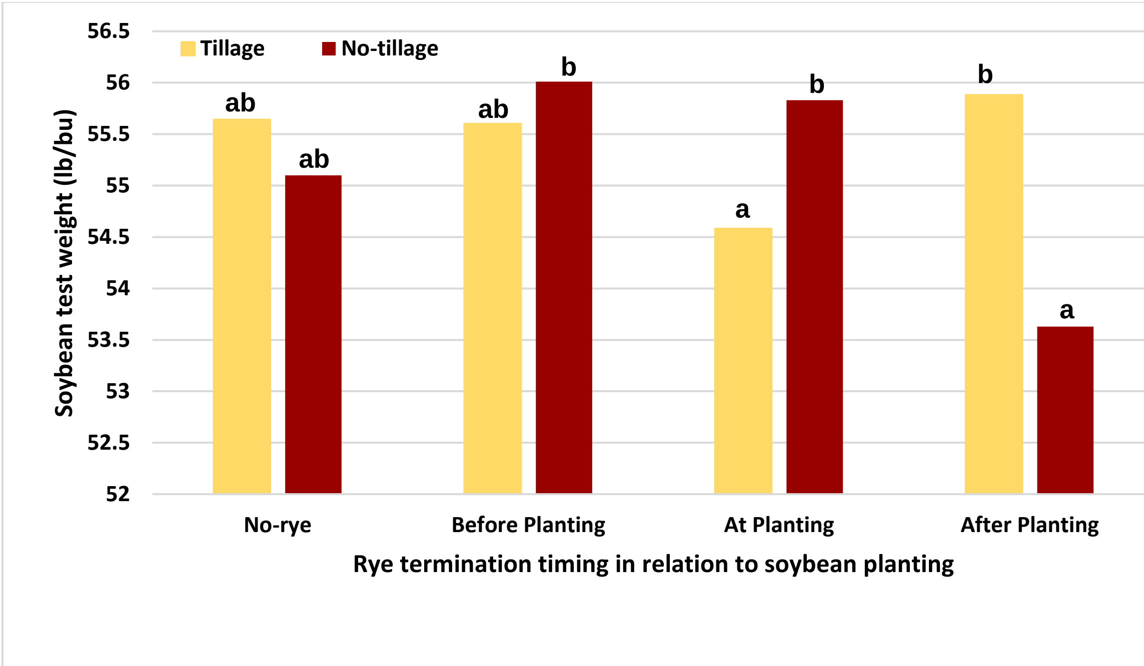

Figure 3. Soybean test weight in no-till and tilled plots either seeded in 2021 with no fall rye or fall rye terminated before, at and after soybean planting in 2022 {*P* = 0.0552, LSD (0.05) = 2.19 lb/bu}; those treatment bars above which sit different letters are significantly different from one another at *P* = 0.05.

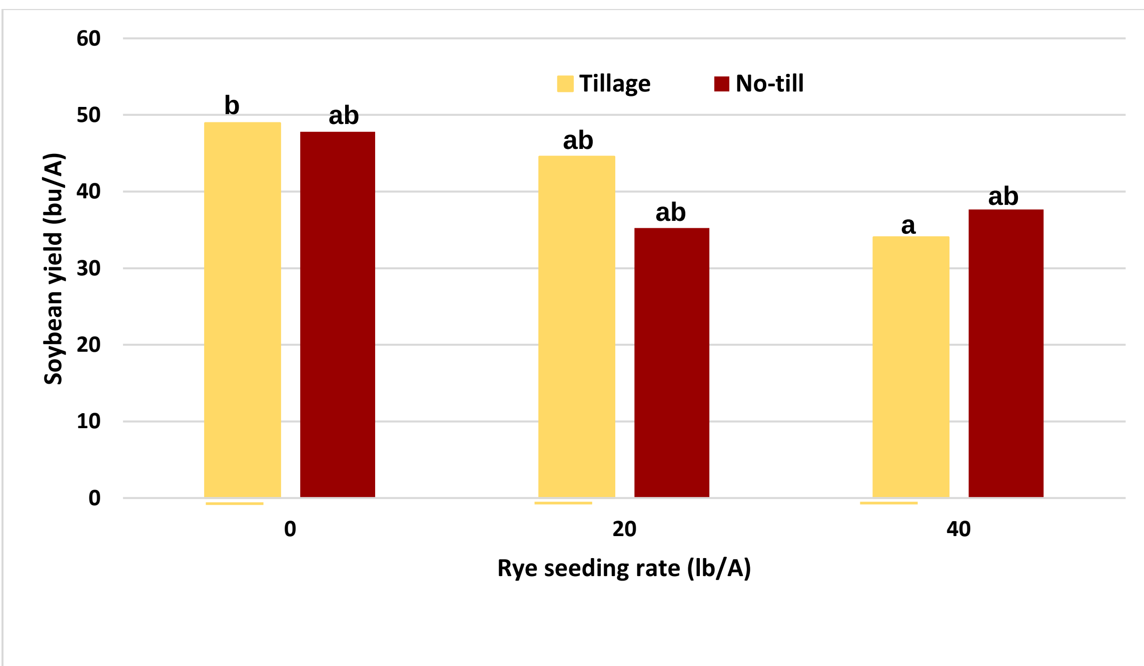

Figure 4. Soybean yield in no-till and tilled plots either seeded in 2021 0, 20 or 40 lb of rye per acre { *P*= 0.0846, LSD (0.10) = 13.86 bu/A}; those treatment bars above which sit different letters are significantly different from one another at *P* = 0.10.

UMN Research & Outreach Center small plot summary *(biomass, stand count, yield, moisture test weight).* The rye cover crop was seeded after an abnormally early harvest of the 2021 wheat crop in northwest Minnesota due to exceptional drought conditions or into a standing corn crop in west-central Minnesota. In spring 2022, soybeans were seeded a month (or more) later than normal due to very wet soil conditions, allowing for considerable rye growth before soybean planting commenced. Only time will reveal how 'typical' the results of this 2021-22 study were.

Rye biomass & soybean stand count. At both research and outreach centers (ROCs) rye terminated at and after soybean planting accumulated statistically similar biomass and significantly more biomass than rye terminated before soybean planting. Soybean stand counts were lowest and statistically similar to one another in plots that either didn't have rye or in which rye was terminated before planting at the NWROC with stand counts in the at-planting termination timing significantly higher and the after-planting stand counts higher still. Rye biomass and stand counts showed opposite trends in tillage treatments at the NWROC with statistically greater rye biomass and lower soybean stand in tilled plots; we theorize that crusting may have been responsible. At the WCROC in which the highest and statistically similar stand counts were observed in the plots with no-rye and rye terminated before planting, the at and after soybean planting rye termination timings significantly similar and lower than in plots with the other treatments – these results are most likely due to the considerable rye biomass shading emerging soybean seedlings.

Soybean yield, moisture & test weight. There were no differences among rye termination timing, tillage or rye seeding rate treatment in soybean yield at either ROC. At the WCROC there was considerable variability associated with treatment means, and so no statistical differences being observed among and between treatments in whole, split and split-split plot treatments is not surprising; the difference between tillage plots at different rye seeding rates – in which statistically higher yields occurred in 0 lb/A rye than in 40 lb/A rye plots is not unexpected, however it is not understood why this same trend didn't follow in no-till plots. The higher grain moisture in plots planted to less rye at the NWROC may have resulted from less rye drying the soil out following the crop through to harvest; this may have also been the same reason why the no-till plots at the NWROC (in which rye less rye accumulated) also resulted in higher test weight.

Stay tuned. Rye was seeded at 3 on-farm locations surrounding each of the two ROCs in fall 2022 and soybean planted 'green' using the same treatments. This project will run both on ROCs and on cooperators' farms through 2025.

Soil health assessments (LaBine and Cates):

We are assessing soil health at the Planting Green sites, focusing on soil samples collected from small plots on the UMN Northwest and West-Central Research & Outreach Centers that were exposed to different tillage regimes, rye seeding rates and termination timings. To cover both biological and physical metrics of soil health, we are using three metrics: aggregate stability, potentially mineralizable carbon, and ACE protein. Aggregate stability is related to the functions of water infiltration and storage, while potentially mineralizable carbon and ACE protein are organic matter pools related to microbial activity and nutrient mineralization. Note that all these properties are expected to change more with consistent application of soil health principles (minimizing disturbance, maximizing living cover), and so the samples we were able to take in the spring after 1 year of cover cropping may not show dramatic changes.

Aggregate stability. More large aggregates indicate greater soil health, as a well-aggregated soil has more pores that allow adequate gas exchange for crop roots, better water infiltration and water storage capacity. When water enters the soil, great force is exerted on aggregates and more stable aggregates can withstand this force, maintaining a soil's resiliency and health, while less stable aggregates are broken apart. Soil aggregates are formed when root exudates feed fungi and bacteria in the rhizosphere. Dead soil bacteria form sticky compounds that help to bind soil particles. Fungal hyphae (long thin strands of fungal cells) and roots help hold large aggregates, and usually intensive tillage decreases aggregation.

Aggregate stability is assessed using a wet sieving process that disrupts aggregate binding and separates soil into several size classes. A greater percentage of the soil remaining in >2mm aggregates, the largest size class, indicates better soil structure. We only sampled 12 weeks after planting as we expected cover crop effects to take time, and the analysis is very time-consuming.

The aggregate stability assessment is finished for the NWROC 12 week samples, although the large aggregate sizes will be corrected for any sand found on the sieve. Data is quite variable, but we tend to see more large aggregates in plots with cover crops (**Figure 5**) . A preliminary statistical model was run for each ROC separately, with termination timing, tillage, and cover crop seeding rate and their interactions as fixed effects and replicate as a random effect. A three-way interaction between termination timing, cover crop seeding rate, and tillage was significant (*P*= 0.02). Generally, pairwise comparisons showed significant differences between no cover crop, and cover crops seeded at 40 lbs/ac, while the 20 lbs/ac cover crop treatment was often similar to no cover crop results.

Potentially mineralizable carbon. Potentially mineralizable carbon (PMC) is a portion of the total soil organic matter pool. PMC is assessed in a 24-hour lab incubation with soil at an ideal temperature and moisture for microbial activity. The CO_2 respired during this time, in mg per g soil, indicates both how active soil microbes are under ideal conditions, and how much simple soil C they have as a food source. Greater PMC generally indicates more healthy soil, and other studies have found increased PMC with soil health practices like reduced tillage and cover crops. PMC is known to change seasonally, somewhat dependent on inputs of carbon from living plants and plant residue as well as temperature and moisture conditions which affect microbes in the field. This was assessed 4 weeks and 12 weeks after planting.

At the five on-farm research locations, PMC was highly variable. All farm data was modeled together with cover crop termination, sample timing, site and their interaction as fixed effects, and replicate as a random effect. Site and timing and their interaction effect were significant ($P<0.0001$ for all). In particular, Appleton and Tintah had greater PMC 12 weeks after planting than 4 weeks after planting, and at some sites, later cover crop termination had greater PMC while some sites had the opposite trend (**Figure 6**). PMC was notably low at Browns Valley relative to all other sites.

At the two ROCs, a preliminary statistical model was run for each ROC separately, with termination timing, sample timing, tillage, and cover crop seeding rate and their interactions as fixed effects and replicate as a random effect. As on-farm, PMC was greater at 12 weeks after planting (significant at $P<0.0001$ in both models). At the NWROC, no other effects were significant (**Figure 7**). At the WCROC, there was a main effect of tillage ($P>0.01$) and a significant tillage x sample timing interaction ($P<0.0001$). No-till plots had greater PMC at 12 weeks after planting than 4 weeks after planting (**Figure 8**). This contrasts with some of our recently published work from Crookston, which found higher PMC values early in the growing season.

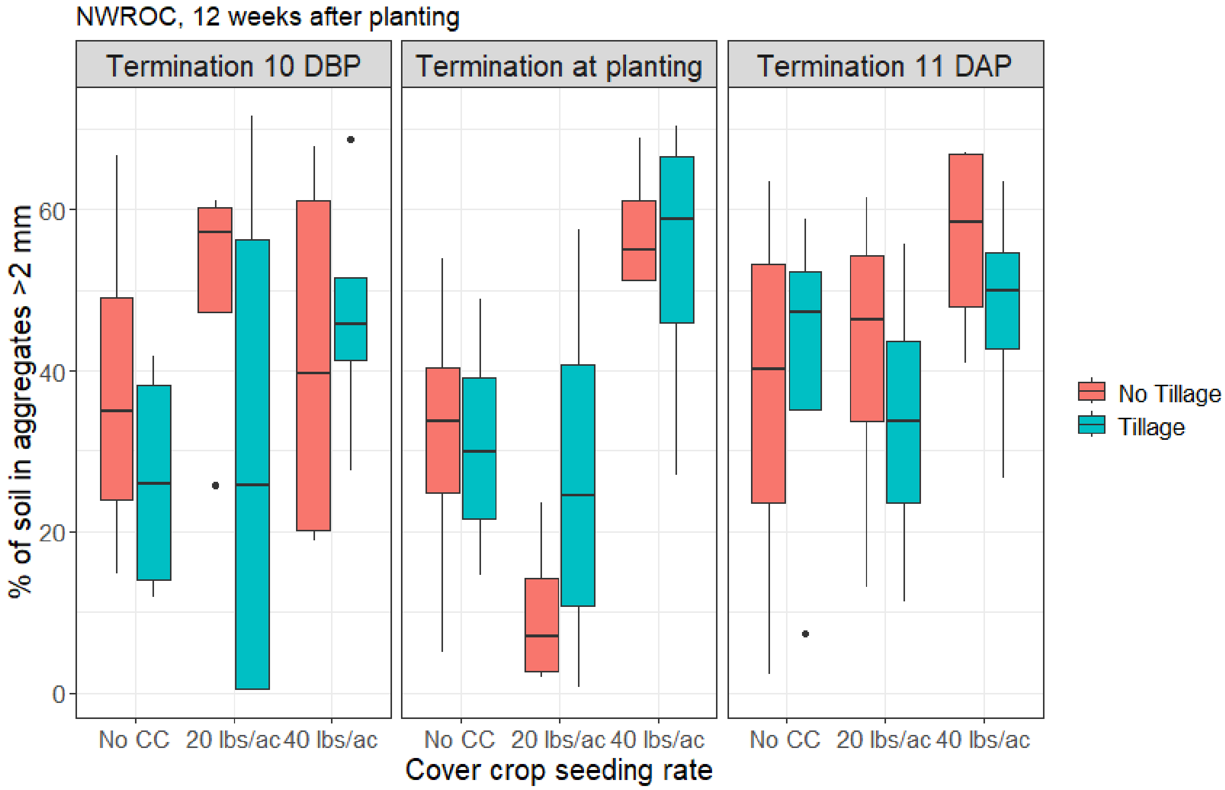

Figure 5. Percentage of soil in aggregates larger than 2 mm in diameter, collected 12 weeks after soybean planting in 2022 at the Northwest Research & Outreach Center. Soil was collected from plots that had different rates of a winter rye cover crop (0, 20, 40 lb/ac) that were drilled in fall 2021, different tillage regimes (fall chisel plow + spring field cultivation or no-till), and different rye termination timing in relation to soybean planting (1-2 week before, at, 1-2 weeks after).

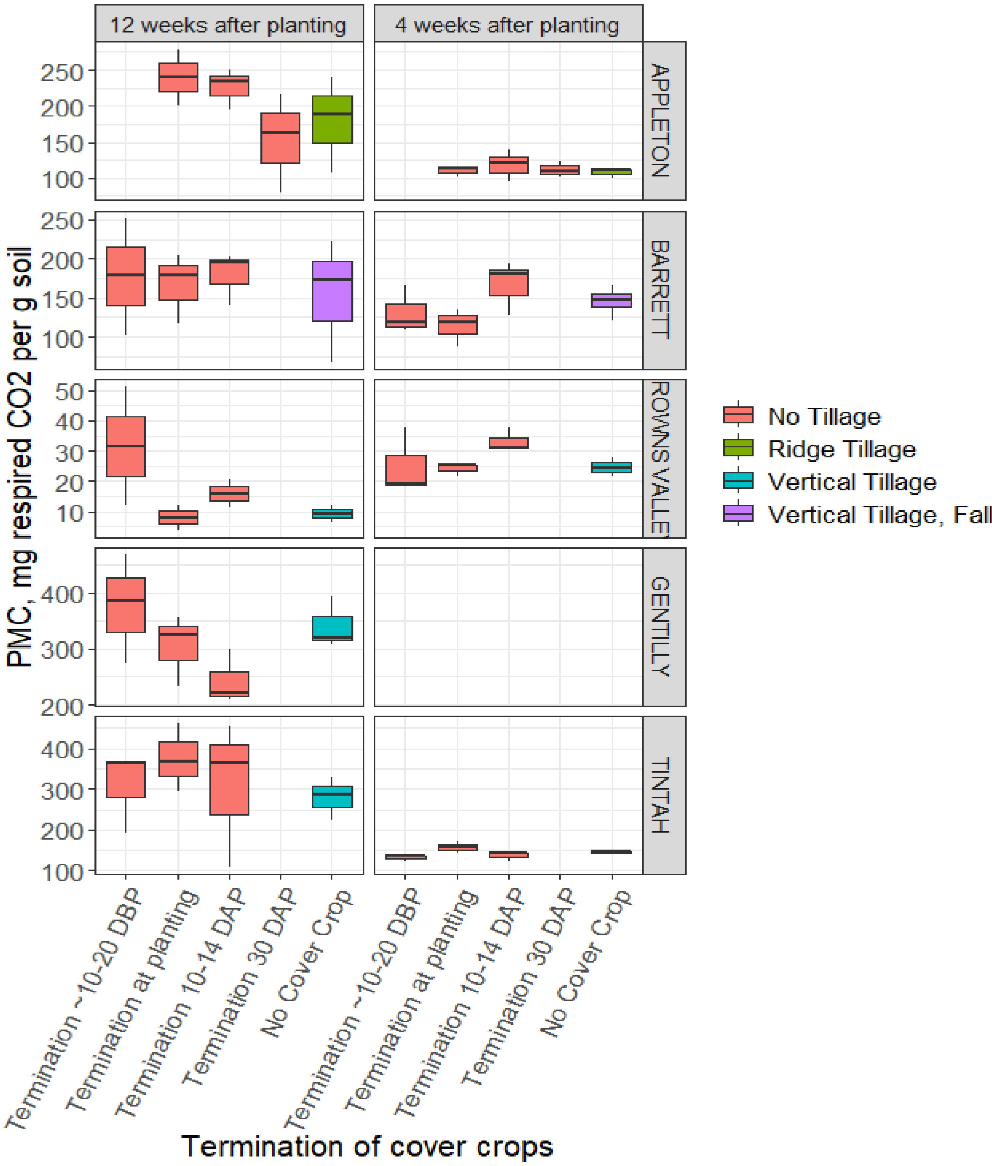

Figure 6. Potentially mineralizable carbon (PMC) on soils collected 4 and 12 weeks after soybean planting in 2022 at five on-farm sites. Soil was collected from plots that had 0 or 30 lbs/ac winter rye cover crop that had been drilled in fall 2021, and different rye termination timing in relation to 2022 soybean planting (1-2 week before, at, 1-2 weeks after). Tillage varied at different sites and treatments.

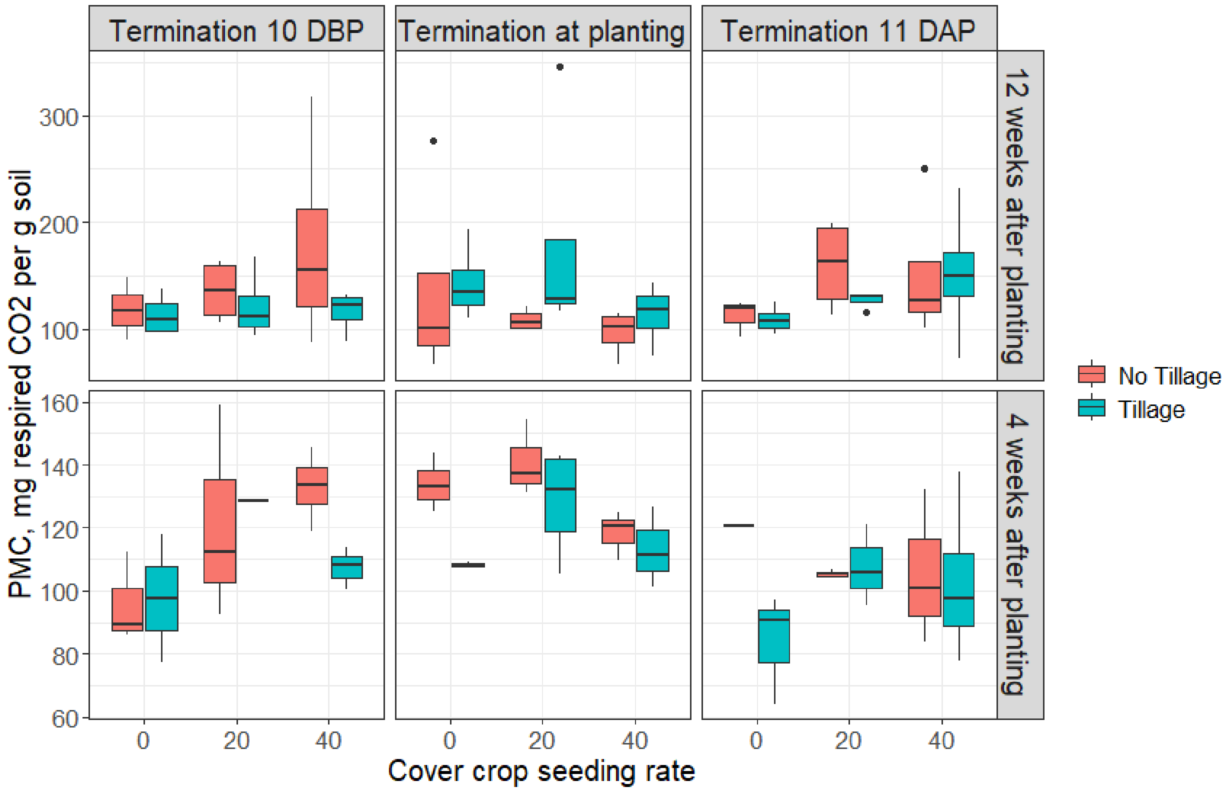

Figure 7. Potentially mineralizable carbon (PMC) on soils collected 4 and 12 weeks after soybean planting in 2022 at the Northwest Research & Outreach Center. Soil was collected from plots that had different rates of a winter rye cover crop (0, 20, 40 lb/ac) that were drilled in fall 2021, different tillage regimes (fall chisel plow + spring field cultivation or no-till), and different rye termination timing in relation to soybean planting (1-2 week before, at, 1-2 weeks after).

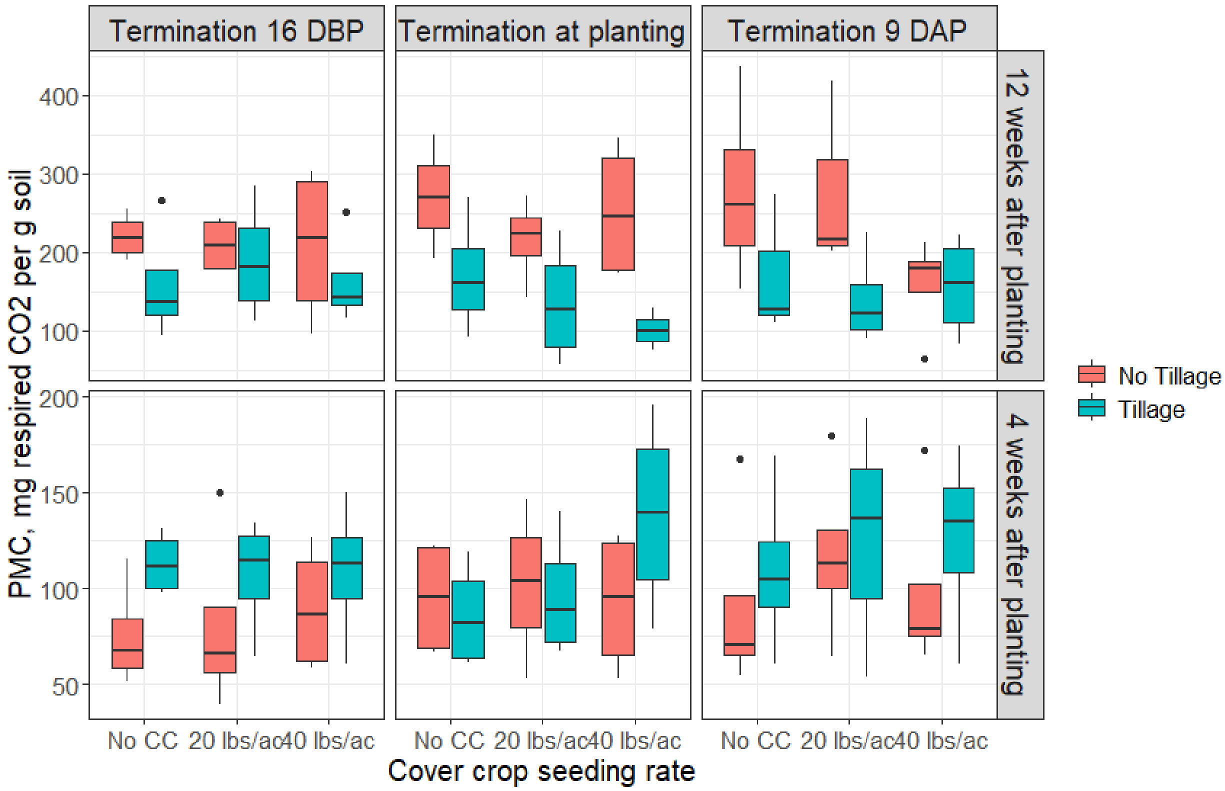

Figure 8. Potentially mineralizable carbon (PMC) on soils collected 4 and 12 weeks after soybean planting in 2022 at the West Central Research & Outreach Center. Soil was collected from plots that had different rates of a winter rye cover crop (0, 20, 40 lb/ac) that were broadcast in fall 2021, different tillage regimes (fall chisel plow + spring field cultivation or no-till), and different rye termination timing in relation to soybean planting (1-2 week before, at, 1-2 weeks after).

Autoclaved citrate-extractable protein. ACE (autoclaved citrate-extractable) protein is extracted via a laboratory reaction with $KMnO_4$, and represents a large pool of organic N, in milligrams of protein per gram soil. More organic N generally indicates a healthier soil. ACE was assessed 4 weeks and 12 weeks after planting.

As of the end of February 2023, all 4-week post-planting samples from the WCROC and NWROC have been analyzed in the lab. There is a trend towards lower values with tillage, and greater values in the plots where cover crops were terminated at planting at the NWROC.

Preliminary statistical models were run separately for each ROC site, with termination timing, tillage, and cover crop seeding rate and their interactions as fixed effects and replicate as a random effect. At the NWROC, tillage and termination timing were marginally significant (P= 0.05 and P=0.06, respectively), and the tillage x termination interaction was significant (P=0.03). Within no-till plots, termination at planting led to greater ACE (**Figure 9**). Within all at-planting termination plots, no-till had significantly greater ACE. No other pairwise comparisons were significant. No significant effects were found at the WCROC (**Figure 10**).

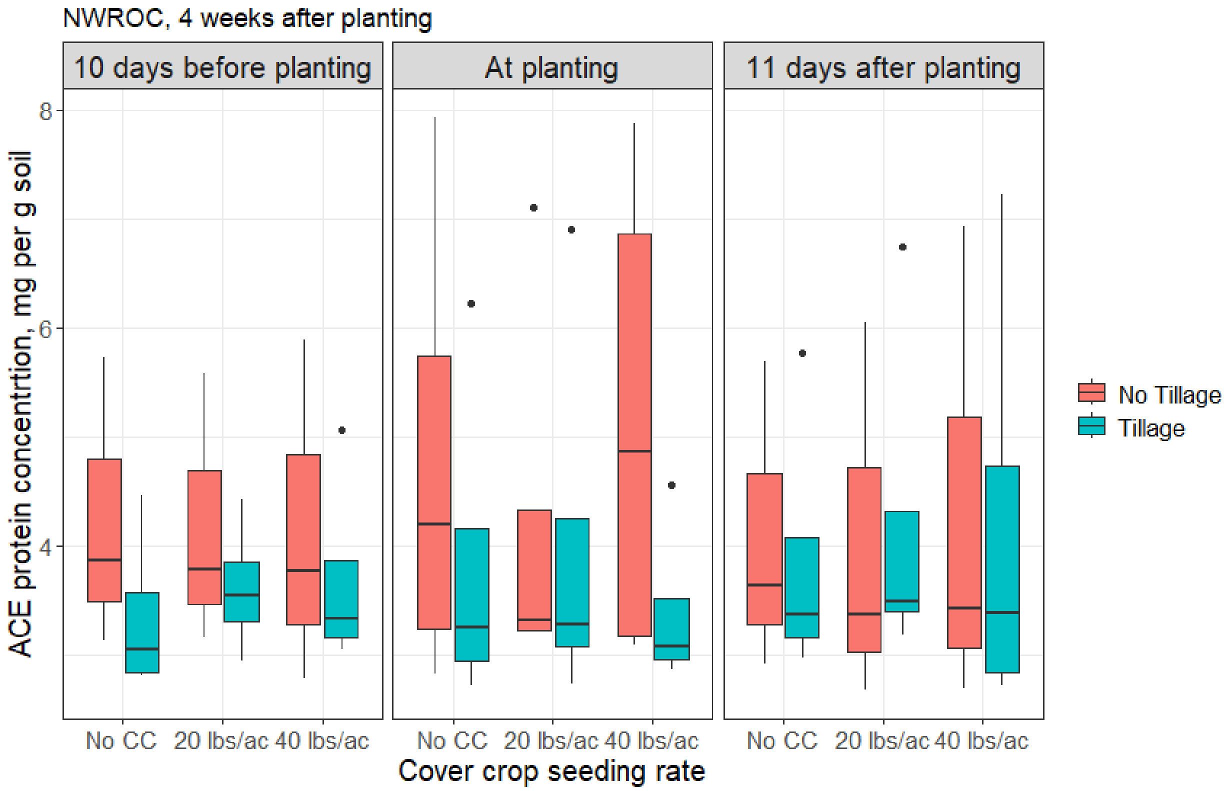

Figure 9. Autoclaved citrate extractable protein measured in soils collected 4 weeks after soybean planting in 2022 at the Northwest Research & Outreach Center. Soil was collected from plots that had different rates of a winter rye cover crop (0, 20, 40 lb/ac) that were drilled in fall 2021, different tillage regimes (fall chisel plow + spring field cultivation or no-till), and different rye termination timing in relation to soybean planting (1-2 week before, at, 1-2 weeks after).

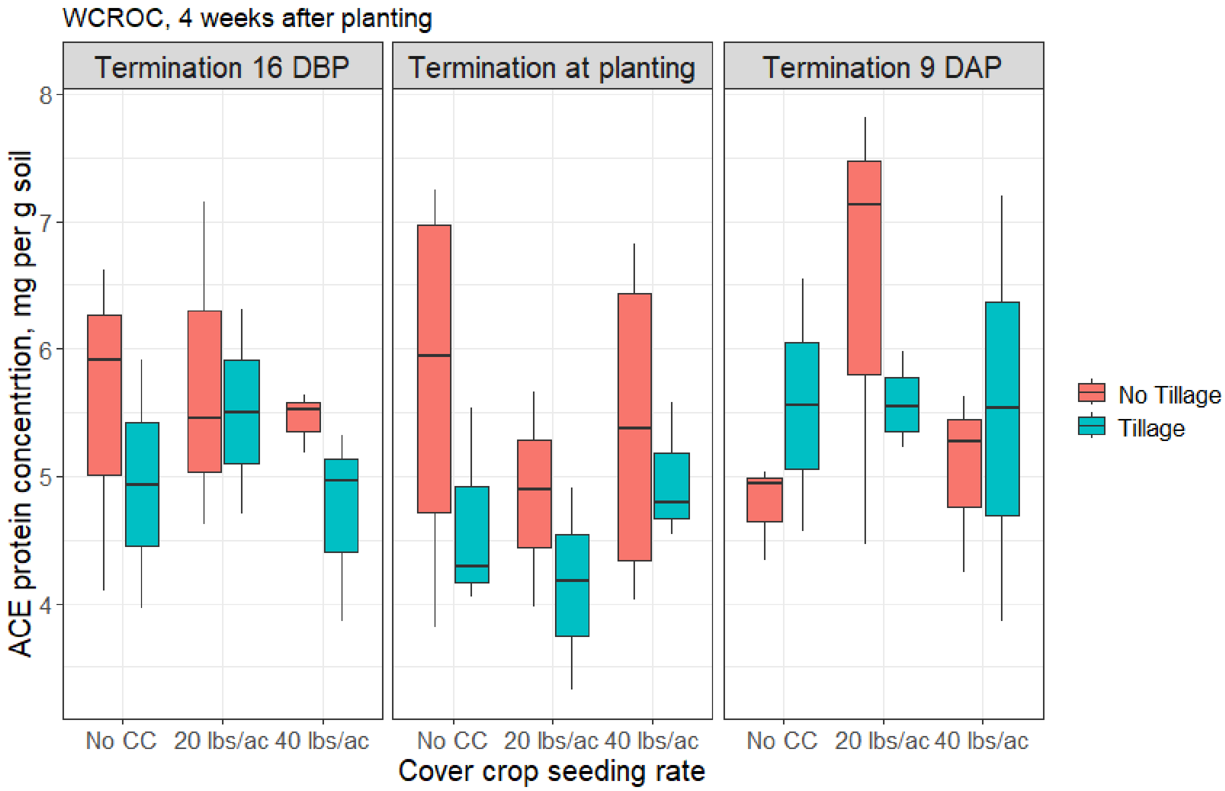

Figure 10. Autoclaved citrate extractable protein measured in soils collected 4 weeks after soybean planting in 2022 at the West-central Research & Outreach Center. Soil was collected from plots that had different rates of a winter rye cover crop (0, 20, 40 lb/ac) that were broadcast in fall 2021, different tillage regimes (fall chisel plow + spring field cultivation or no-till), and different rye termination timing in relation to soybean planting (1-2 week before, at, 1-2 weeks after).

Soil nutrient cycling (Loss, Reitmeier, Pease):

Composite soil samples were collected 4 weeks after soybean planting and after soybean harvest in 2022 to a depth of 6 inches at the University of Minnesota Northwest & West Central Research & Outreach Centers located in Crookston and Morris, MN, respectively. Samples were then analyzed using the KCl method to extract nitrate (NO_3^{2-}), a form of nitrogen that is both plant-available and therefore at risk of leaching loss. Samples were also analyzed for phosphorus content using the Olsen method. Results from the NWROC have been completed at this time.

When the cover crop was terminated in relation to soybean planting also had an effect on soil nitrate concentration, with more nitrate found 4 weeks after soybean planting in the plots that had the longest period in which to begin being degraded by soil microbes, the 1-2 weeks before soybean planting termination timing (**Figure 11**). The rye in these earliest terminated plots was still in the vegetative growth stages at termination and so likely had a C:N ratio lower than the rye in the plots terminated later, making it more easily degraded.

There was a historically severe drought in northwest Minnesota in 2021, likely resulting in residual nitrate remaining from the poorly-yielding wheat that had grown in the field that was then seeded to winter rye for this trial. The plots that were tilled in fall 2021 impacted soil nitrate content after soybean harvest in 2022, with more nitrate in the plots that had been tilled in 2021 than had been planted to winter rye, which likely took up much of the remaining nitrate from 2021 (**Figure 12**).

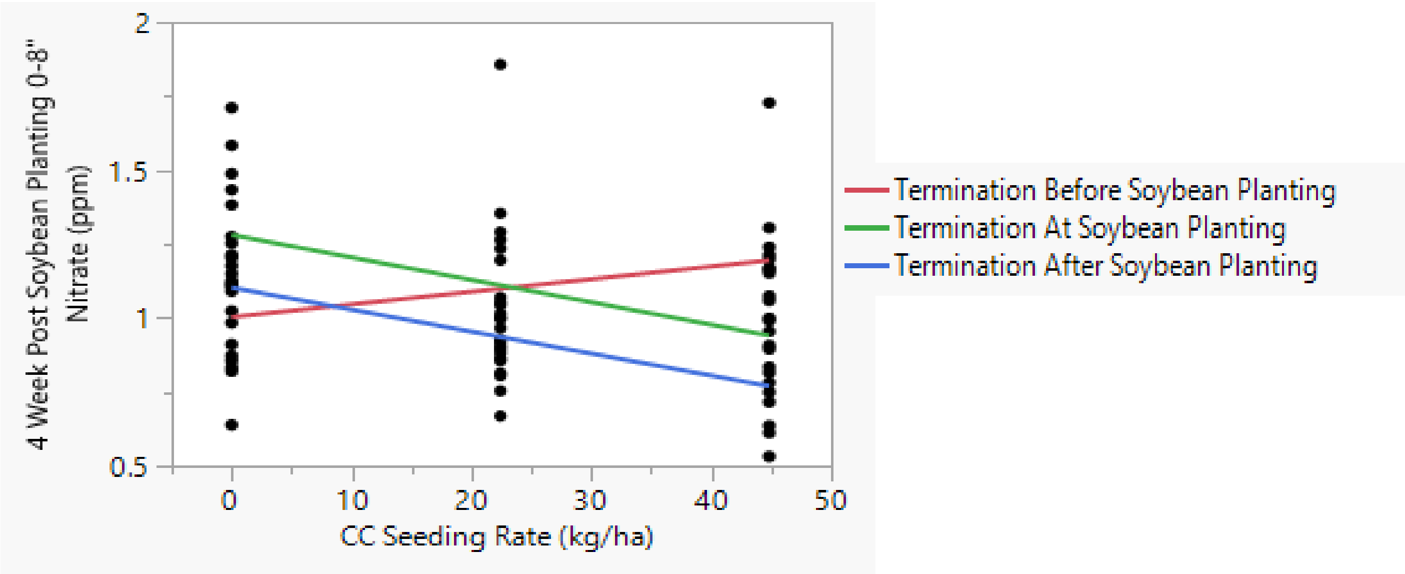

Figure 11. KCl extracted nitrate concentration (in parts per million) in 6 inch soil samples collected 4 weeks after soybean planting in 2022 at the Northwest Research & Outreach Center. Soil was collected from plots that had different rates of a winter rye cover crop (0, 20, 40 lb/ac) that were broadcast in fall 2021, different tillage regimes (fall chisel plow + spring field cultivation or no-till), and different rye termination timing in relation to soybean planting (1-2 week before, at, 1-2 weeks after).

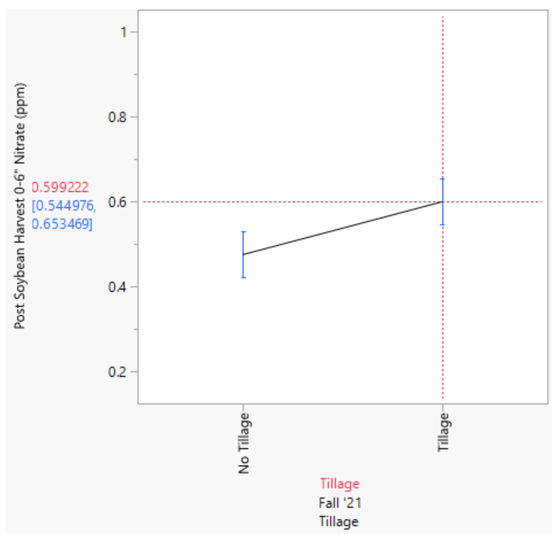

Figure 12. KCl extracted nitrate concentration (in parts per million) in 6 inch soil samples collected after soybean harvest in 2022 at the Northwest Research & Outreach Center. Soil was collected from plots in which the soil was either fall chisel plowed + spring field cultivated or planted no-till to a winter rye cover crop and different rye termination timing in relation to soybean planting (1-2 week before, at, 1-2 weeks after).

None of the treatments impacted the soil Olsen phosphorus concentration. This is likely due to the fact that the calcareous, very high pH soils at the study location tends to tie up plant-available phosphate.