FARMER-DRIVEN RESEARCH INTO PLANTING GREEN ALONG THE RED

Institution/Organization: Regents of the University of Minnesota

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Experimental Design:

Treatments were arranged as large strips wide enough to accommodate farmer's equipment in a randomized complete block design with three replications. While nutrient cycling & soil health data were also collected, here are reported rye biomass at termination, soybean stand count, yield, moisture & test weight data.

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

Here we summarize the effect of cover crop termination timing on rye biomass, soybean stand count and seed moisture, test weight and yield.

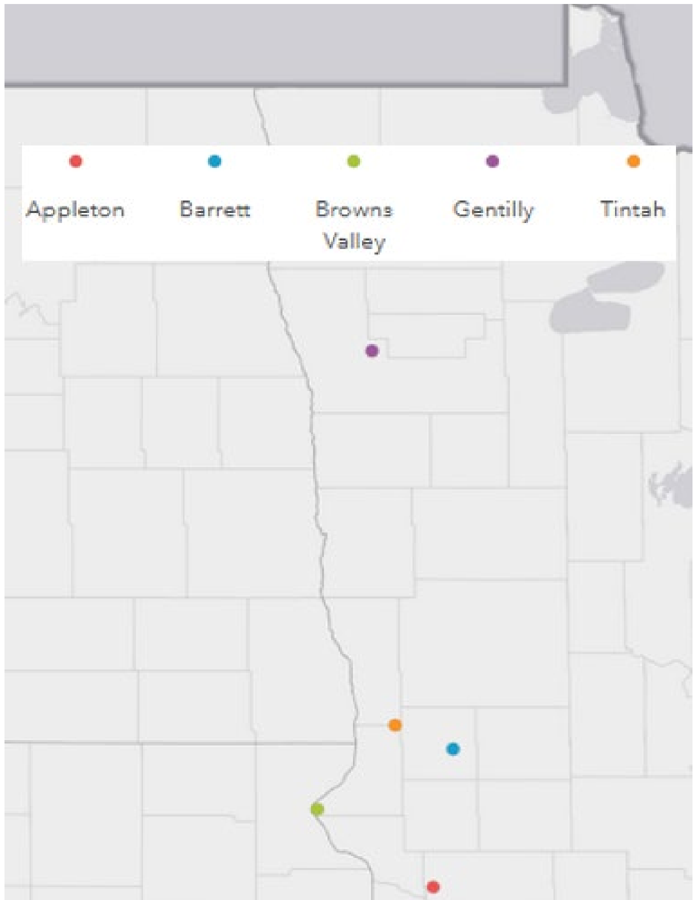

Figure 1. On-farm trial locations in 2021-2022.

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 a 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 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 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.

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.

Rye biomass & soybean stand count. 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.

Soybean yield, moisture & test weight. 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.

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 1**) . 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.

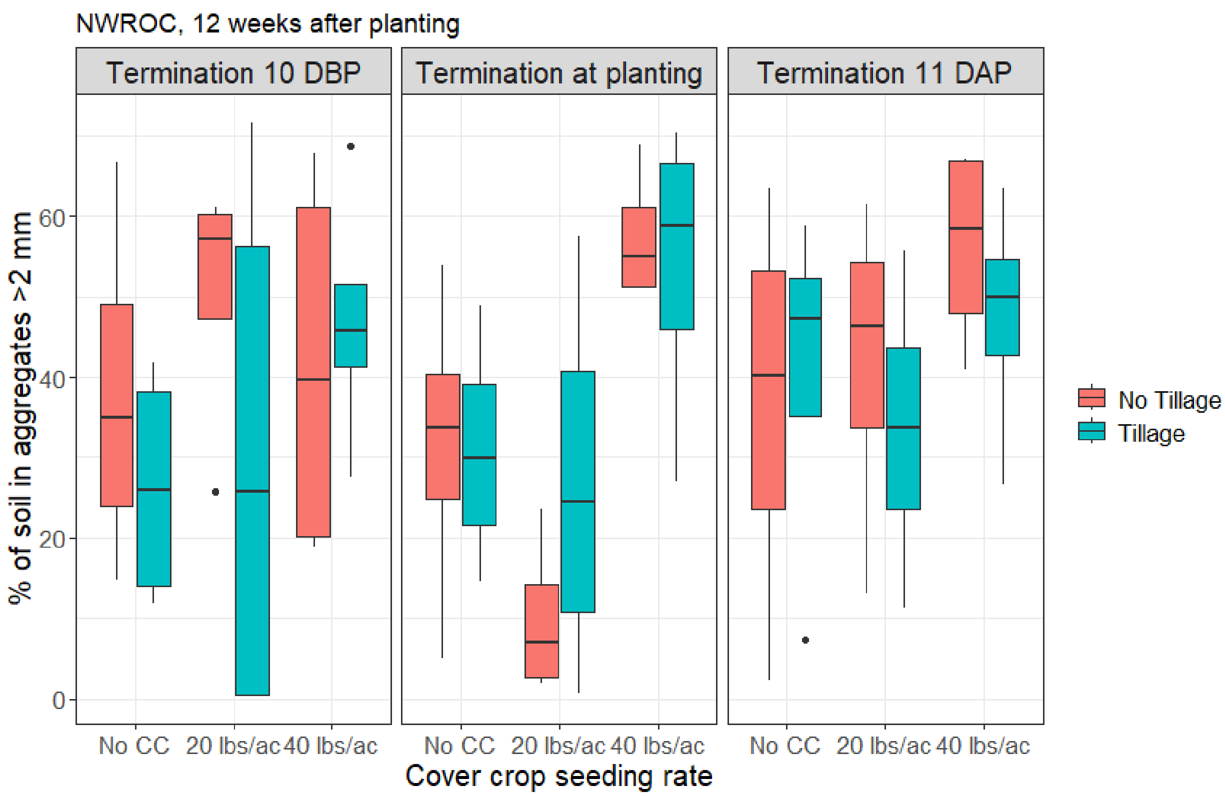

Figure 1. Percentage of soil in aggregates larger than 2 mm in diameter, collected 12 weeks after soybean planting in 2022 at the Northwest Research & Outreach Center. Soil was collected from plots that had different rates of a winter rye cover crop (0, 20, 40 lb/ac) that were drilled in fall 2021, different 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).

<u>Potentially mineralizable carbon.</u> 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 2**). PMC was notably low at Browns Valley relative to all other sites.

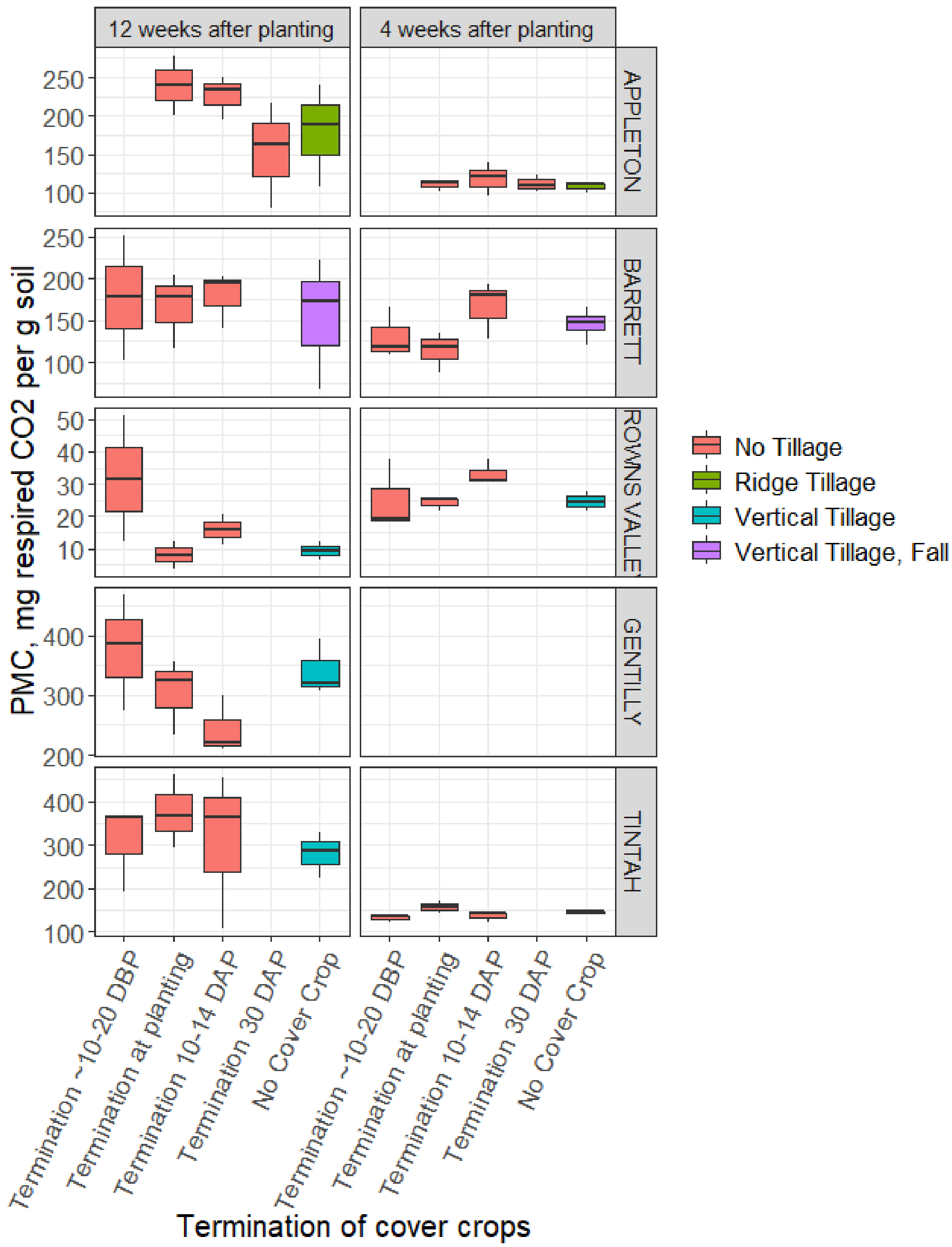

Figure 2. Potentially mineralizable carbon (PMC) on soils collected 4 and 12 weeks after soybean planting in 2022 at five on-farm sites. Soil was collected from plots that had 0 or 30 lbs/ac winter rye cover crop that had been drilled in fall 2021, and different rye termination timing in relation to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

soybean planting (1-2 week before, at, 1-2 weeks after). Tillage varied at different sites and treatments.

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 3**). 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 4**). This contrasts with [some of our recently published work from Crookston,] which found higher PMC values early in the growing season.

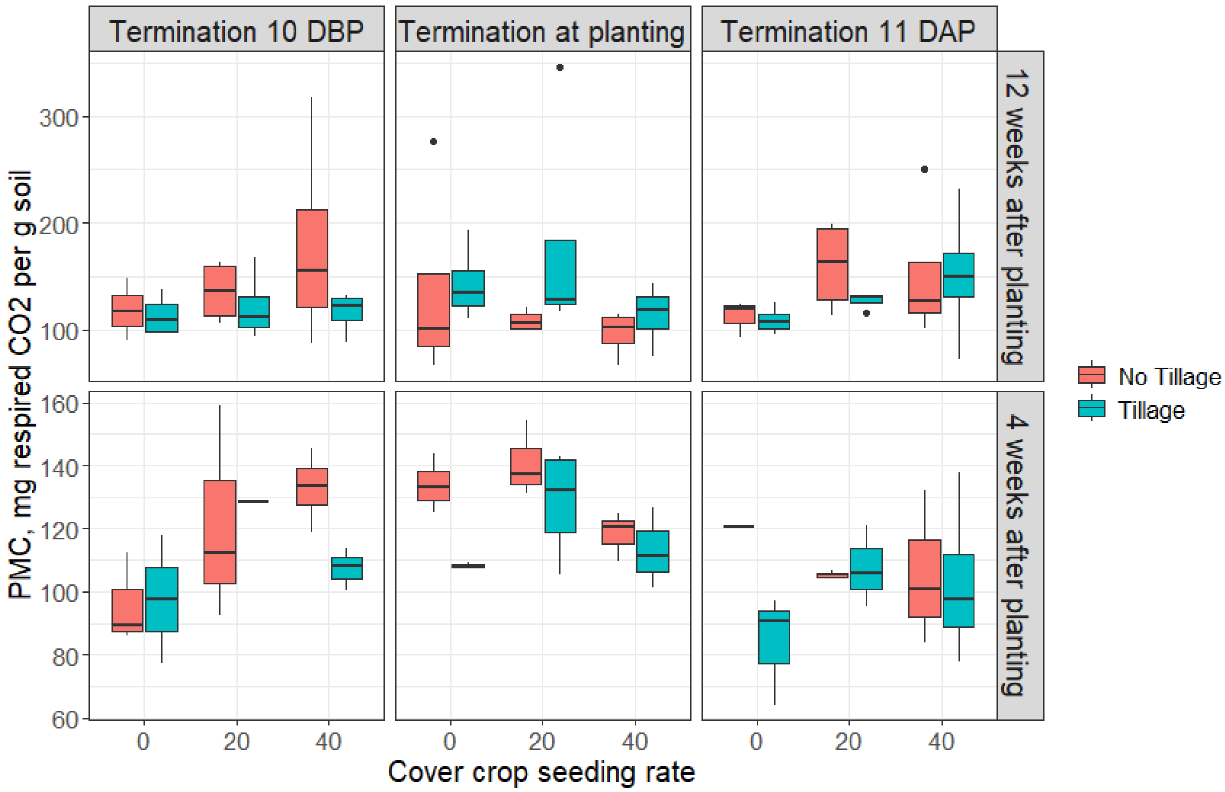

Figure 3. Potentially mineralizable carbon (PMC) on soils collected 4 and 12 weeks after soybean planting in 2022 at the Northwest Research & Outreach Center. Soil was collected from plots that had different rates of a winter rye cover crop (0, 20, 40 lb/ac) that were drilled in fall 2021, different 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).

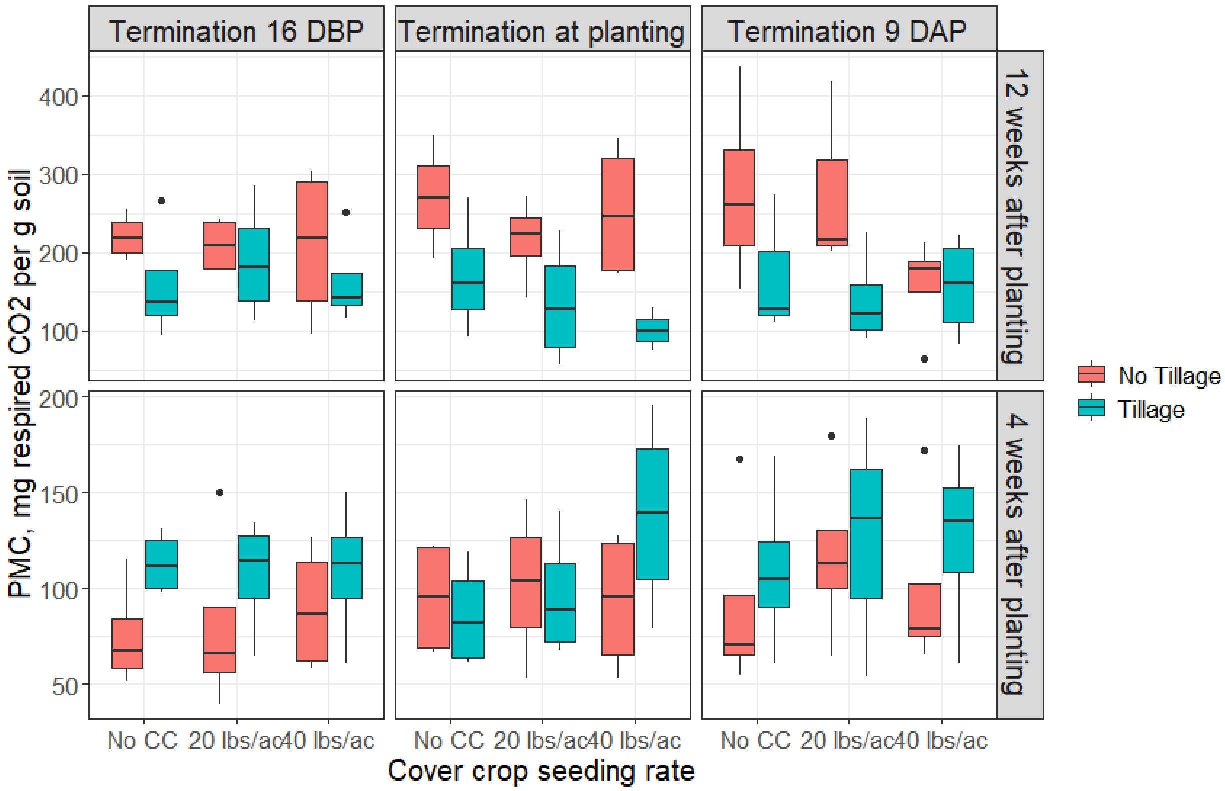

Figure 4. Potentially mineralizable carbon (PMC) on soils collected 4 and 12 weeks after soybean planting in 2022 at the West Central Research & Outreach Center. Soil was collected from plots that had different rates of a winter rye cover crop (0, 20, 40 lb/ac) that were broadcast in fall 2021, different 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).

<u>Autoclaved citrate-extractable protein.</u> 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 5**). 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 6**).

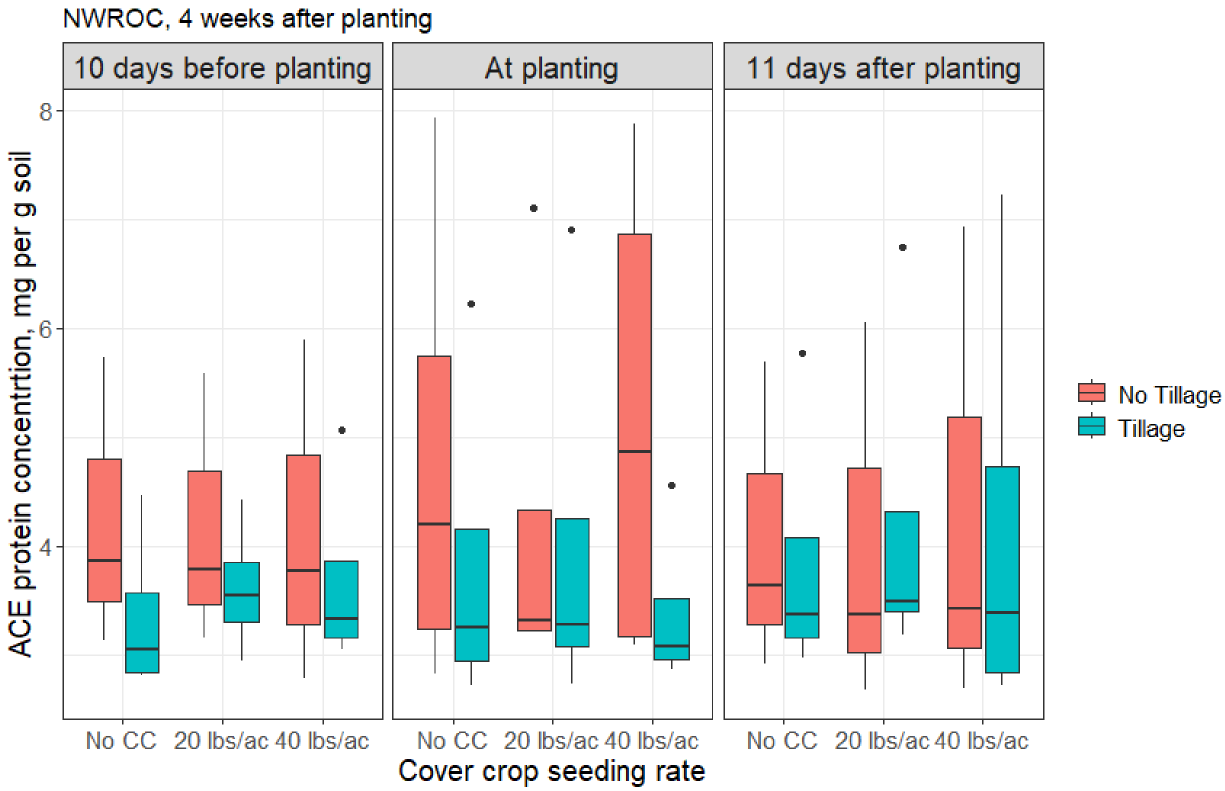

Figure 5. Autoclaved citrate extractable protein measured in soils collected 4 weeks after soybean planting in 2022 at the Northwest Research & Outreach Center. Soil was collected from plots that had different rates of a winter rye cover crop (0, 20, 40 lb/ac) that were drilled in fall 2021, different 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).

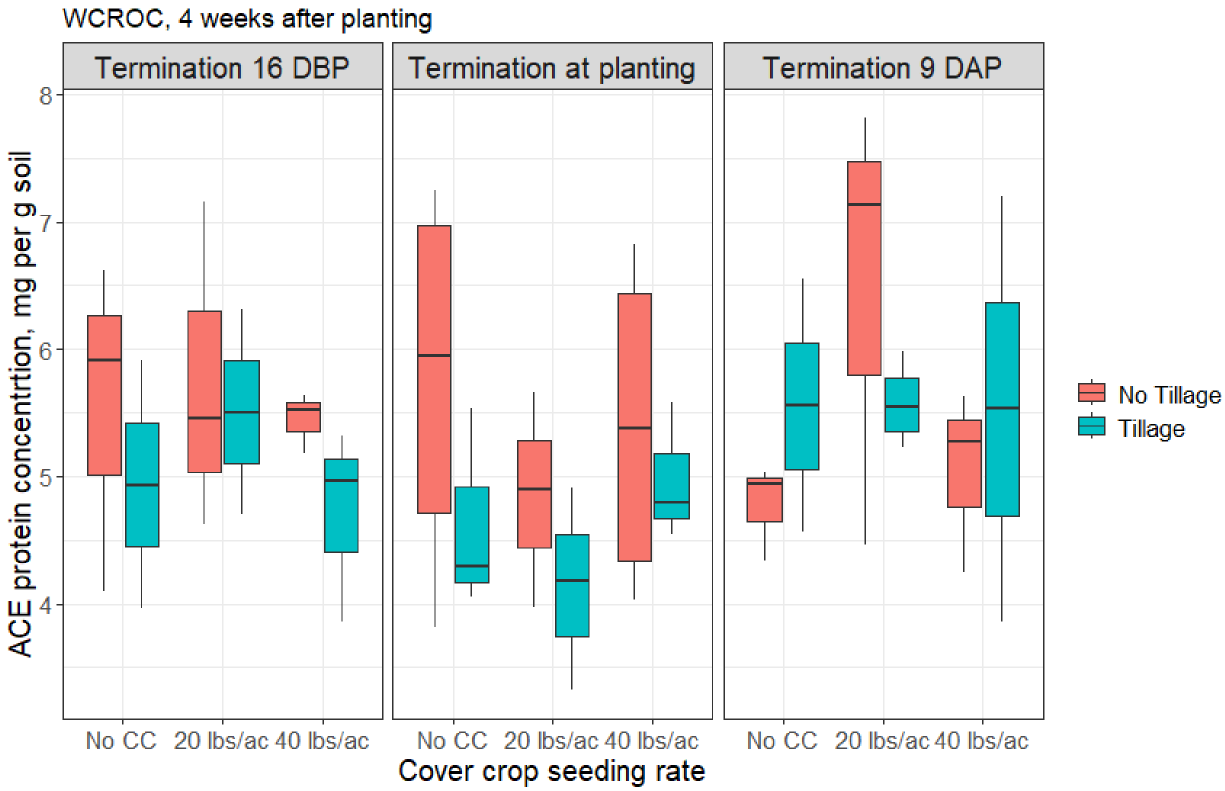

Figure 6. Autoclaved citrate extractable protein measured in soils collected 4 weeks after soybean planting in 2022 at the West-central Research & Outreach Center. Soil was collected from plots that had different rates of a winter rye cover crop (0, 20, 40 lb/ac) that were broadcast in fall 2021, different 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 7**). 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 8**).

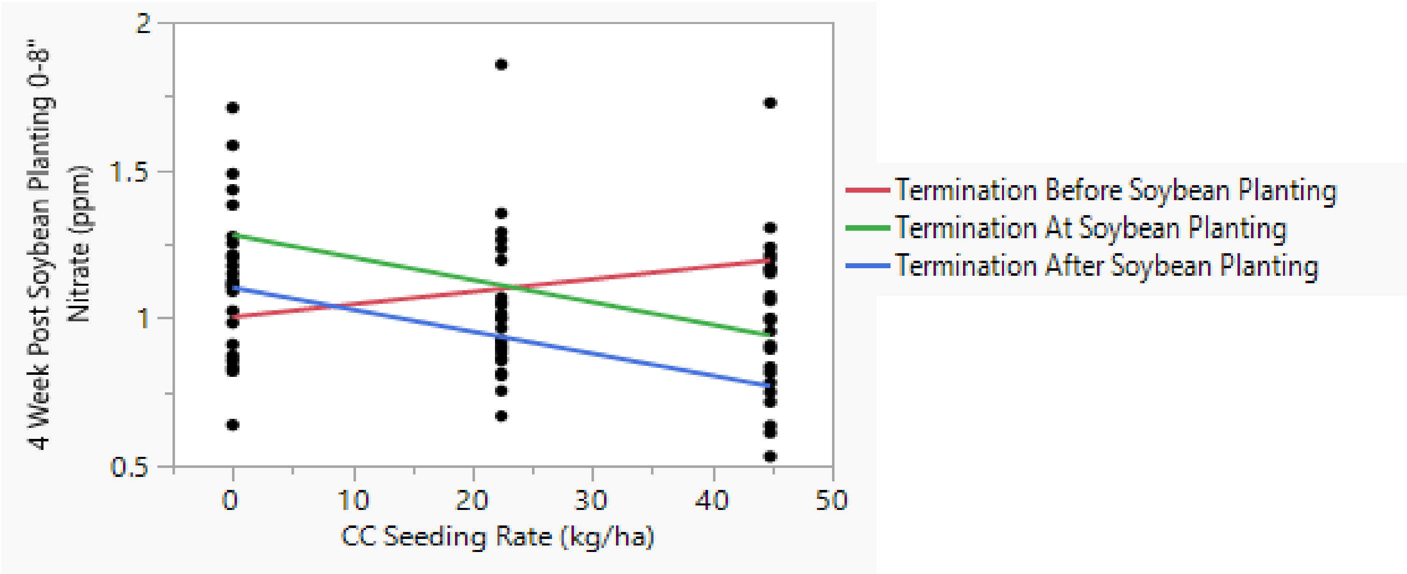

Figure 7. KCl extracted nitrate concentration (in parts per million) in 6 inch soil samples collected 4 weeks after soybean planting in 2022 at the Northwest Research & Outreach Center. Soil was collected from plots that had different rates of a winter rye cover crop (0, 20, 40 lb/ac) that were broadcast 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).

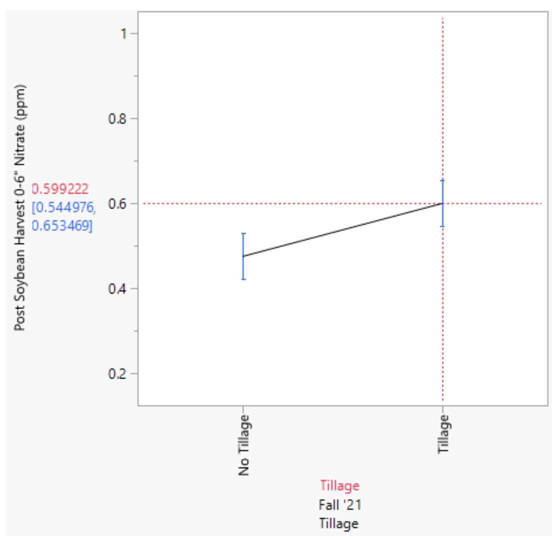

Figure 8. KCl extracted nitrate concentration (in parts per million) in 6 inch soil samples collected after soybean harvest in 2022 at the Northwest Research & Outreach Center. Soil was collected from plots in which the soil was either fall chisel plowed + spring field cultivated or planted no-till to 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.

Lastly, although there was a trend toward lower yield with later cover crop termination, neither the different tillage treatments, nor the different winter rye seeding rate treatments nor the different winter rye termination timing treatments had an impact on soybean yield at the at the Northwest Research & Outreach Center (**Figure 9**).

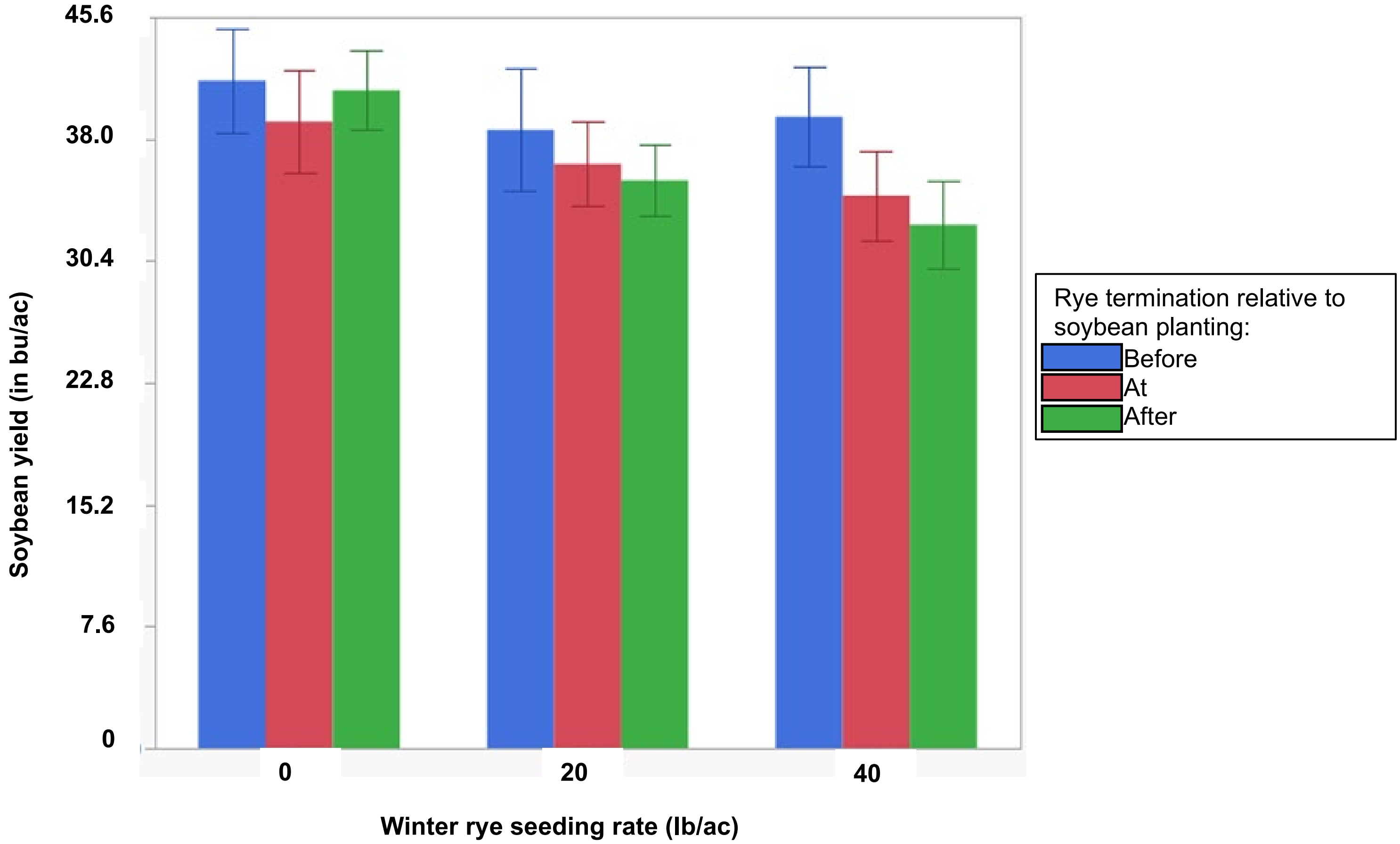

Figure 9. Soybean yield in 2022 at the Northwest Research & Outreach Center in plots that had different rates of a winter rye cover crop (0, 20, 40 lb/ac) that were drilled in fall 2021, different tillage regimes (fall chisel plow + spring field cultivation or no-till), and different rye termination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

Stay tuned. Rye was seeded at 3 on-farm locations surrounding each of the two ROCs in fall 2022 in anticipation of planting soybean "green" for further study in 2023. This project will run both on ROCs and on cooperators' farms through 2025.