**Report Submitted to the South Dakota Nutrient Research and Education Council – 2018 Season**

**Project Title:** Sulfur and Nitrogen Dynamics for Rye Raised as a Cover Crop

**Investigators:** Peter Sexton, Anthony Bly, Peter Kovacs, David Karki, and Sara Bauder
(SDSU Southeast Research Farm, SDSU Extension and Agronomy, Hort. & Plant Sci. Dept,)

**Project Duration to Date:** January through December, 2018

**Summary** *(as written in the original proposal)*
Cereal rye used as a cover crop in the corn/soybean rotation is increasingly popular among farmers. Rye has the advantages of being very winter hardy, keeping the ground covered and benefiting soil health while putting on rapid growth early in the spring. The rapid spring growth of rye brings into question its impact on nitrogen and sulfur availability for the following cash crop. It is well-known that rye sequesters nitrogen (N) and will generally increase N requirements for a following corn crop. For this reason, we have not advocated the use of rye ahead of corn. Rye ahead of soybeans is more robust as soybeans fix their own N so that is not a limitation; however, in work at the Southeast Farm in 2016, we observed that sulfur (S) content was lower in soybeans grown after rye when compared with control plots. This is consistent with observations we have made in previous years that soybeans following late-killed rye are sometimes slightly yellower in August as compared to control plots. We have not seen any yield loss from this, but it raises the question of whether S may be a factor limiting soybean response to the rye cover crop. As rye has demonstrated itself to be a robust and practical cover crop, there are questions that need to be addressed about the nutrients it sequesters - in this case we are particularly interested in S ahead of soybeans – but we will measure other nutrients as well. Preliminary analysis of data from the current season (2017) shows a yield response to S (applied as ammonium sulfate near emergence delivering 5 lb/ac of sulfur) for soybeans following a rye cover crop at the Southeast Farm (Peter Kovacs, personal communication).

**Objectives** *(as written in the original proposal)*

1.) Determine the extent of sulfur sequestration by cereal rye cover crop.
2.) Develop estimates of optimum rye burndown timing for soybean;
3.) Evaluate soybean response to supplemental S following a rye cover crop.

**Results and Impacts**

Three field trials were initiated to help meet the objectives listed above. Two of the trials (the rye seed rate trial and on-farm trials with supplemental S) were completed in the 2018 season. The third trial with burndown timing was lost due to heavy rains in June which inundated the field where the trial was located. The results for the two completed trials were included in the annual report for the Southeast Research Farm and are given below.

# Seeding Rate for Rye Cover Crop Ahead of Soybeans

Ben Brockmueller*, Peter Sexton, and Brad Rops,

## INTRODUCTION

Winter rye has found a place in cropping systems in the Upper Midwest due to its strong winter hardiness, easy establishment, and vigorous production of biomass in early spring growth. Winter rye has proved itself to be a viable option for growers looking to increase qualities of soil health and nutrient use efficiency through the use of cover crops. Rye, being a grass, is a nitrogen user and scavenges the soil for free nitrogen that is subject to losses in the system. Previous experience with rye has shown that it has the potential to sequester nutrients, specifically nitrogen and sulfur, ahead of the subsequent cash crop. In order to further explore this question, research has been conducted to examine different management systems that address these questions. One option is to look at optimal seeding rates of winter rye that provide the expected ecosystem services desired through the use of a cover crop, while maintaining adequate levels of soil moisture and nutrients for the following soybean crop.

## METHODS

Rye (Rymin) was drilled into corn stalks on November 13, 2017 following harvest at the Southeast Research Farm. A Randomized Complete Block Design was used with 5 sets of treatments replicated 4 times. Seeding rate treatments of rye were 20 lbs/ac, 40 lb/ac, 60 lb/ac, 80 lb/ac, and a control of no rye. Rye was burned down in all plots on May 22, 2018 using a burndown herbicide (glyphosate and metolachlor). Soybeans were no-tilled into the rye the following day (May 23, 2018). Biomass of rye, duff, and soybeans were collected throughout the growing season to further track the rates of decomposition and nutrient content of the material. Rye biomass was collected on May 18 and May 24, 2018. Soybean biomass was collected on July 30, 2018 (R2) and September 10, 2018 (R6) in order to determine nutrient content of the soybeans at specific points in the growing season. Duff samples were collected on May 24, July 30, and September 10, 2018 to observe the rate of decomposition and ensuing release of nutrients into the soil. Grain harvest occurred on October 18, 2018 and grain yield was measured using a Kincaid 8XP Plot Combine.

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## RESULTS

Yields for the control (no rye) treatment and highest rye seeding rate treatment (80 lb/ac) averaged 3 bu/ac more than the other treatments. However, we did not observe any linear trend showing that soybean yield was affected either positively or negatively as rye seeding rate increased.

Rye biomass in the spring was lower than expected due to a late planting date (November 13) and unfavorable growing conditions in the spring (Table 1). Due to low rye production, and therefore low rye residue amounts in 2018, it will be interesting to observe if more vigorous rye growth resulting from favorable growing conditions and an earlier planting date in the future will result in a more linear prediction of yield based on seeding rate.

Additionally, further work in 2019 will explore how quickly these rye residues will decompose back into the soil and make the nutrients they hold plant available. The nutrient content of the rye residues, previous crop residues, and soybeans will be analyzed at specific points throughout the growing season to attempt to find a clearer picture of the fate of nutrients in the system and whether the soybean crop will be deficient of any nutrients caused by immobilization in rye residues.

## ACKNOWLEDGEMENTS

The authors express appreciation to the Nutrient Research and Education Council (NREC) and the South Dakota Agricultural Experiment Station who supported this research.

**Table 1**: Observed rye residue biomass at burndown time. Rye residue samples were taken in two locations per plot for a total collection area of 6 $ft^2$. Rye burndown occurred on May 22, 2018 and soybeans were green-planted into rye on May 23, 2018.

| Average Biomass Weights (lb/ac) | |
|---|---|
| Seeding Rate (lb/ac) | Dry Matter (lb/ac) |
| 0 | 0 |
| 20 | 224 |
| 40 | 400 |
| 60 | 216 |
| 80 | 460 |

**Table 2**: Stand at harvest, moisture, test weight, 100 seed weight, and yield for soybeans no-till planted into rye residue. Rye was terminated on May 22, 2018 and soybeans were planted the following day on May 23, 2018. Five seeding rate treatments were utilized, 0 lb/ac, 20 lb/ac, 40 lb/ac, 60 lb/ac, 80 lb/ac.

| Seeding Rate | Plant Population | Moisture | Test Weight | 100 Seed Weight | Yield |
|---|---|---|---|---|---|
| (lb/ac) | (plants per acre) | (%) | (lb/bu) | (g) | (bu/ac) |
| 0 | 151589 | 11.9 | 48.4 | 14.9 | 69.2 |
| 20 | 118483 | 11.9 | 49.1 | 16.1 | 66.3 |
| 40 | 123710 | 11.4 | 46.0 | 15.0 | 66.9 |
| 60 | 118483 | 11.5 | 47.4 | 14.7 | 66.7 |
| 80 | 121968 | 11.3 | 44.5 | 14.6 | 69.3 |
| *Mean* | 126846.7 | 11.58 | 47.035 | 15.06 | 67.67 |
| *CV (%)* | 20.9705 | 3.82 | 5.96 | 7.64 | 2.23 |
| *p-value* | 0.3879 | 0.27 | 0.19 | 0.393 | 0.03 |
| *LSD* | NS | NS | NS | NS | 2.27 |

SOUTHEAST RESEARCH FARM ANNUAL REPORT
*South Dakota State University*
2018 Progress Report
Agricultural Experiment Station
Plant Science Department
South Dakota State University, Brookings, SD 57007
Southeast Research Farm, Beresford, SD 57004

# Sulfur and Nitrogen Applications on Soybeans Following Rye Cover Crop

Ben Brockmueller[†], Peter Sexton, and Brad Rops

## INTRODUCTION

There has been an increase in winter rye cover cropping in the upper Midwest due to its role in promoting soil health. One benefit of rye is its ability to take up and sequester mobile nutrients such as nitrogen and sulfur that could be lost from a system through leaching. Nitrogen and sulfur are converted into organic forms in the plant and released back into the soil as the tissues decompose. Previous experience has shown that rye has the potential to sequester nitrogen and sulfur leaving these nutrients slightly deficient in the following crop. Continued research into the burndown timing of rye informs how early before planting the subsequent crop that rye should be terminated to best match the nutrient release of rye with the needs of the crop. A preliminary study was done to assess the response of nitrogen and sulfur fertilizers on soybean yield when applied following a rye cover crop.

## METHODS

This study was initiated at the Southeast Research Farm and in two different producer fields. Rye was planted as a cover crop in the three plot locations. A Randomized Complete Block Design was used with 7 fertilizer treatments replicated four times at each location. The sulfur fertilizer treatments were structured to deliver either 0, 10, or 20 lb per acre of S. Because ammonium sulfate also delivers N along with S, two treatments with urea were included to deliver an equivalent amount of N as was in the ammonium sulfate treatments. The treatments were as follows: 1) Control – no extra fertilizer applied; 2) equivalent 10 lb per acre as Urea (N only); 3) equivalent 20 lb per acre as Urea (N only); 4) 10 lb per acre of S as Ammonium Sulfate; 5) 20 lb/acre of S as Ammonium Sulfate; 6) 10 lb per acre of S as Magnesium Sulfate 7) 20 lb per acre of S as Magnesium Sulfate.

At the Southeast Research Farm location, a cover crop of Rye (Rymin) was no-till seeded using a drill on 07 November, 2017. It was then terminated using a burndown herbicide (glyphosate and metolachlor) on 18 May, 2018. Soybeans were no-till seeded on 31 May 2018. Grain harvest occurred on 29 October, 2018 and grain yield was measured using a Kincaid 8 XP Plot Combine.

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## RESULTS

Yield data from the three locations is shown in Table 1. None of the locations showed any statistically significant difference in yields based on fertilizer treatments. However, there appeared to be a trend towards higher yields with more nitrogen applied. Using only sulfur instead of nitrogen as applied in Magnesium sulfate tended to average a few bushels per acre less than the treatments which contained nitrogen. While none of these differences were deemed significant at any of the three locations, it does offer insight into the role of rye in sequestering nutrients and the ability of supplemental fertilizers to provide a yield increase. This work will be continued into 2019 to provide a better snapshot of the nutrient content of soybean plants and the ability of supplemental fertilizers to bridge yield gaps that may be caused by rye's sequestration of nitrogen and sulfur.

## ACKNOWLEDGEMENTS

The authors appreciate the contributions of the South Dakota Agricultural Experiment Station and Nutrient Research and Education Council (NREC) for this research and to the local producers (Christensen and Tornberg) for participating in this research project.

**Table 1**: Average yields for each of the fertilizer treatments at each of the three locations. The sulfur fertilizer treatments were structured to deliver either 0, 10, or 20 lb per acre of S. Because ammonium sulfate also delivers N along with S, two treatments with urea were included to deliver an equivalent amount of N as was in the ammonium sulfate treatments. The treatments were as follows: 1) Control – no extra fertilizer applied; 2) equivalent 10 lb per acre as Urea (N only); 3) equivalent 20 lb per acre as Urea (N only); 4) 10 lb per acre of S as Ammonium Sulfate; 5) 20 lb/acre of S as Ammonium Sulfate; 6) 10 lb per acre of S as Magnesium Sulfate 7) 20 lb per acre of S as Magnesium Sulfate. Rye was planted in the fall of 2018 at each location and sprayed out two weeks before planting. Soybeans were no-till drilled into rye residue.

| **Christensen Field** | | **Tornberg Field** | | **SE Research Farm** | |
|---|---|---|---|---|---|
| Treatment | Yield (bu/ac) | Treatment | Yield (bu/ac) | Treatment | Yield (bu/ac) |
| Urea 20 | 66.3 | Urea 20 | 59.2 | Urea 20 | 61.0 |
| Urea 10 | 65.3 | Ammonium Sulfate 10 | 58.3 | Urea 10 | 60.9 |
| Ammonium Sulfate 20 | 65.1 | Urea 10 | 57.8 | Magnesium Sulfate 10 | 57.1 |
| Ammonium Sulfate 10 | 64.7 | Magnesium Sulfate 20 | 57.5 | Magnesium Sulfate 20 | 56.6 |
| Magnesium Sulfate 20 | 64.0 | Ammonium Sulfate 20 | 57.4 | Control 0 | 56.0 |
| Magnesium Sulfate 10 | 62.5 | Magnesium Sulfate 10 | 55.6 | Ammonium Sulfate 10 | 55.8 |
| Control | 62.3 | Control | 55.3 | Ammonium Sulfate 20 | 52.1 |
| *Mean* | 64.3 | *Mean* | 57.3 | *Mean* | 56.8 |
| *CV* | 7.7 | *CV* | 4.6 | *CV* | 19.5 |
| *p-value* | 0.894 | *p-value* | 0.41 | *p-value* | 0.94 |
| *LSD* | NS | *LSD* | NS | *LSD* | NS |

## Changes in Project or Personnel

We added a rye variety component to the project in the fall of 2018. Twelve lines of rye were seeded in replicated plots to measure genotypic differences in biomass production and nutrient uptake among the different varieties. We will seed soybeans into these plots after taking measurements of rye biomass when the rye is at the boot stage. This will allow us to see if there are differences among rye varieities in nutrient uptake and in how they impact yield of the following soybean crop. God willing, this will provide information on rye variety selection to round out information on rye seed rates, burndown dates, and utility of S fertilizer amendments so growers will have a more complete set of data to make decisions from.

In terms of personnel, Mr. Ben Brockmueller who grew up on a farm near Freeman, South Dakota, started working on the field trials in August of 2018. Ben is doing a good job and the work has been progressing well since he joined the project. We have did have some temporary delays due to the federal government shutdown which closed the USDA-ARS lab in Brookings where he has been working with Dr. Shannon Osborne on plant tissue analysis.

## Products (publications, presentations, disclosures/patents)

None thus far. The project has only completed its first year of field work.

## Budget Matters.

An extension was given on the budget to allow for sample analysis from the 2018 season, which is on-going due to the late start of the graduate student on this project. So the budget cycle for the first year has not closed yet.

**Dec. 2020 final report - submitted to the South Dakota Nutrient Research and Education Council**

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**Project Duration to Date:** January, 2018 through December, 2020

**Summary** *(as written in the original proposal)*
Cereal rye used as a cover crop in the corn/soybean rotation is increasingly popular among farmers. Rye has the advantages of being very winter hardy, keeping the ground covered and benefiting soil health while putting on rapid growth early in the spring. The rapid spring growth of rye brings into question its impact on nitrogen and sulfur availability for the following cash crop. It is well-known that rye sequesters nitrogen (N) and will generally increase N requirements for a following corn crop. For this reason, we have not advocated the use of rye ahead of corn. Rye ahead of soybeans is more robust as soybeans fix their own N so that is not a limitation; however, in work at the Southeast Farm in 2016, we observed that sulfur (S) content was lower in soybeans grown after rye when compared with control plots. This is consistent with observations we have made in previous years that soybeans following late-killed rye are sometimes slightly yellower in August as compared to control plots. We have not seen any yield loss from this, but it raises the question of whether S may be a factor limiting soybean response to the rye cover crop. As rye has demonstrated itself to be a robust and practical cover crop, there are questions that need to be addressed about the nutrients it sequesters - in this case we are particularly interested in S ahead of soybeans – but we will measure other nutrients as well. Preliminary analysis of data from the current season (2017) shows a yield response to S (applied as ammonium sulfate near emergence delivering 5 lb/ac of sulfur) for soybeans following a rye cover crop at the Southeast Farm (Peter Kovacs, personal communication).

**Objectives** *(as written in the original proposal)*
1.) Determine the extent of sulfur sequestration by cereal rye cover crop.
2.) Develop estimates of optimum rye burndown timing for soybean;
3.) Evaluate soybean response to supplemental S following a rye cover crop.

**Results and Impacts**

The overall goal of this project as indicated above was to study the effects of a cereal rye cover crop and its management on the nutrient dynamics of the following soybean crop. This involved field trials at the Southeast Research Farm looking at rye seed rate and burndown timing in the 2018 and 2019 seasons. These trials included nutrient analysis of rye tissue and also of the soybean crop near flowering and at maturity to measure effects on nutrient balance of the soybean crop. The project also involved trials looking at S response of soybeans at on-farm sites near Beresford in 2018, and in Yankton and Arlington in 2019. The results of these trials were compiled and analyzed in detail by Ben Brockmueller for his Master's thesis (159 pages) which is available on-line at (https://openprairie.sdstate.edu/etd/4094/). This report will summarize the main points from this project. The reader is referred to the thesis cited above for a full compilation of the data collected from the rye seed rate and burndown timing studies. The project also involved trials looking at S response of soybeans at on-farm sites near Beresford in 2018, and in Yankton and Arlington in 2019. The S response studies were summarized in the annual reports of the Southeast Research farm for the 2018 and 2019 seasons. These reports are also available at the SDSU 'Open Prairie' web site (https://openprairie.sdstate.edu/agexperimentsta_rsp/).

***Rye Seed Rate and S Sequestration.***

Rye biomass in the spring was weakly responsive to seed rate between 22 and 67 kg/ha (20 to 60 lb/ac) in this study; the 90 kg/ha (80 lb/ac) seed rate did show higher biomass (Fig. 1). The C:N ratio of the rye cover crop increased as biomass increased in both seasons (Fig. 1). The C:N ratio is negatively associated with rate of decomposition and nutrient release from crop residues. The observation that C:N ratio increases with the amount of biomass present means that at higher levels of biomass the rye residue will tend to be more resistant to decomposition (everything else being equal).

The amount of S present in crop residues (corn stover) at the time of soybean planting tended to decrease with increasing rye biomass in both seasons of the study (Fig. 2). The amount of S in crop residue in early September (which at that point includes rye residue along with corn stover) tended to decrease with increasing seed rate in 2018, but not in 2019. In 2018 rye cover crop growth was much less than in 2019; less than 500 lb/ac in 2018 for all treatments while in 2019 all the rye cover crop treatments had more than 1000 lb/ac of biomass (Fig. 1). From these observations, we postulate that the rye cover crop accelerated biological activity and rate of corn stover decomposition in the spring (less corn stover with more rye biomass) and that at low levels of rye biomass (2018 season) this effect was strong enough that by the end of the season (Sept. samples) actually more S was turned over and released in the cover crop plots than in the control plots. In 2019 however, with higher levels of rye biomass, it appears that the balance between rate of decomposition versus amount of S taken up by the rye cover crop was such that S was sequestered by the rye cover crop (more S found in crop residue at the end of the soybean growth cycle for the cover crop versus the control plots - Fig. 2).

This is also reflected in the S status of the soybean crop measured at the R3 growth stage in 2018 and 2019 (Table 1). In 2018 (low rye biomass) we see no effect of the rye cover crop on total above-ground S (kg/ha) in the soybean crop, and actually greater S concentrations in the plots that had a rye cover crop. In 2019 (higher levels of rye biomass) we see a trend for the opposite, where total above-ground S in the soybean crop decreased with use of a rye cover crop and S concentration tended to decline with use of a rye cover crop. It is interesting to note that P levels in the soybean crop appeared to follow similar trends, tending to show no effect or else higher levels of P with use of a rye cover crop in 2018, but in 2019 (with higher levels of rye biomass) the P status of the soybean crop at the R3 stage appeared to be lower with use of a rye cover crop. These effects tended to decline as the crop matured and by the end of the season there was no clear effect of rye cover crop use on soybean yields.

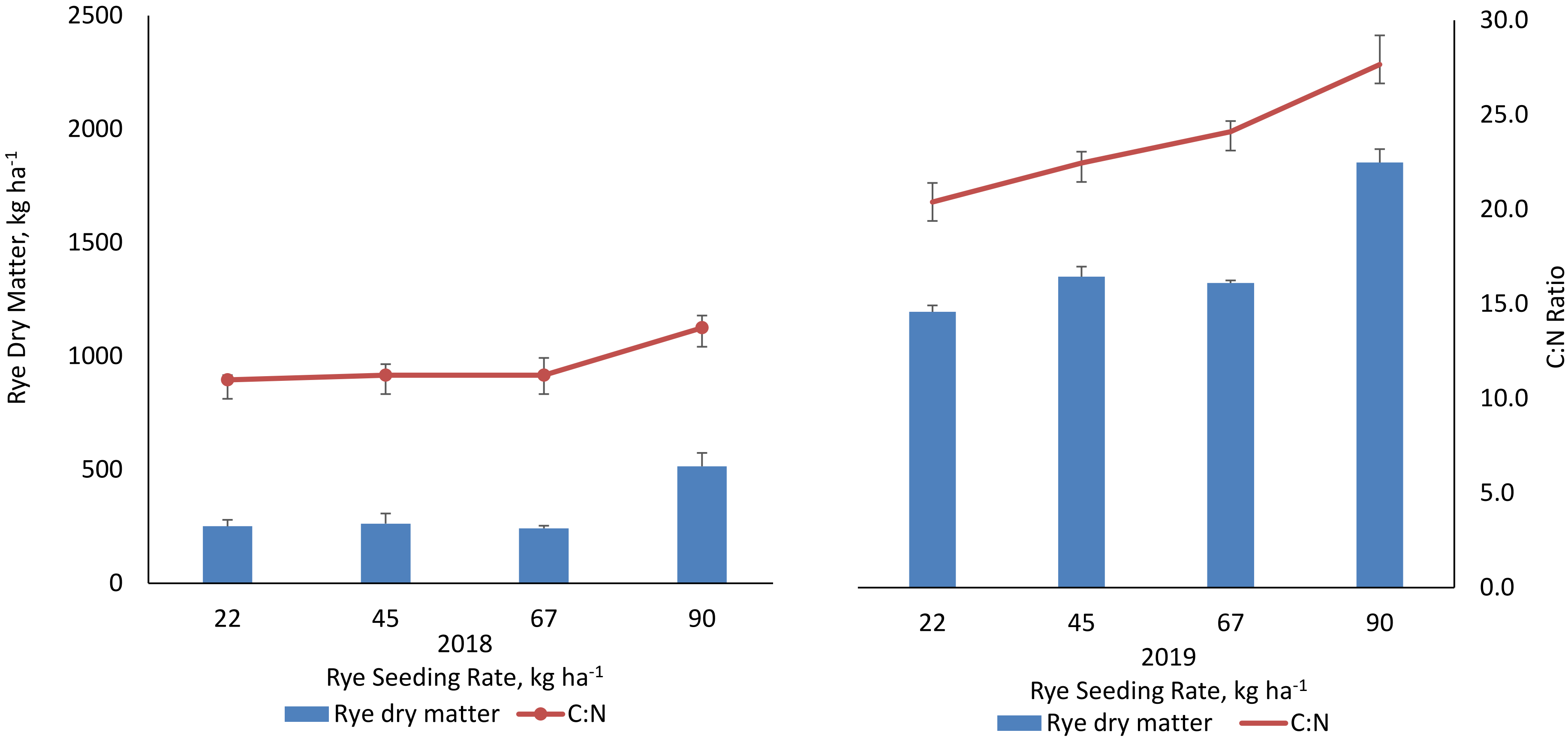
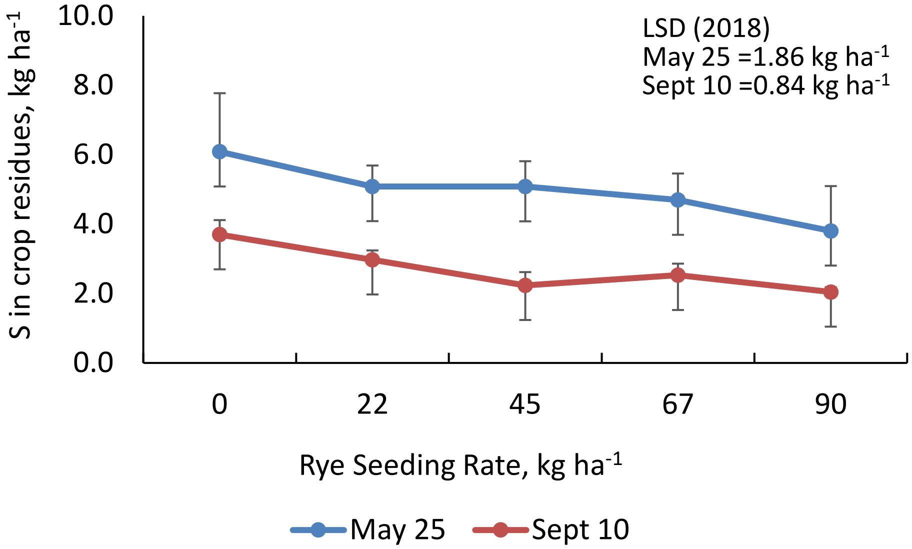



Figure 1. Rye dry matter production and C:N ratio measured at rye termination located at the Southeast Research Farm near Beresford, SD, 2018-2019.



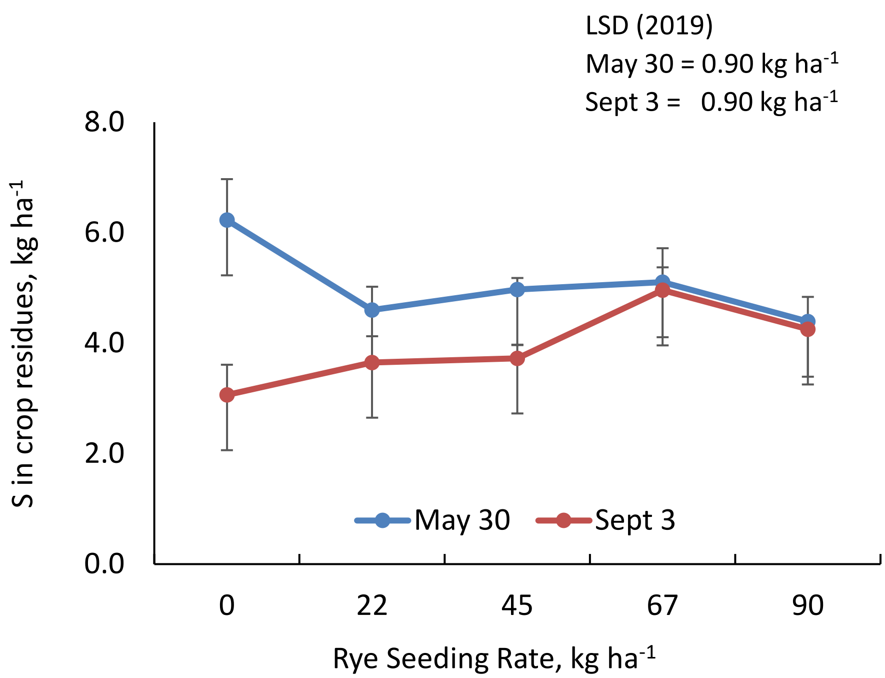




Fig. 2. The amount of S in crop residues versus rye seed rate treatment in studies conducted using rye as a cover crop ahead of soybeans at the Southeast Research Farm in 2018 and 2019. The spring measurement of crop residue includes only corn stover as the rye was living at the time of measurement. The fall measurement would include both corn and rye cover crop residues remaining in the field.

Table 1. Primary nutrient concentration and uptake of soybeans at 5 rye seeding rate treatments measured at the R3 soybean growth stage located at the Southeast Research Farm near Beresford, SD, 2018-2019.

| Year | Seeding Rate | Biomass | N | P | K | S | N | P | K | S |
|---|---|---|---|---|---|---|---|---|---|---|
| 2018 | kg ha$^{-1}$ | kg ha$^{-1}$ | ------------------------g kg$^{-1}$ | | | ---------------------- | ---------------------kg ha$^{-1}$ | | | ------------------- |
| | 0 | 8368 $^{NS}$ | 32.9 $^{NS}$ | 2.69 $^{NS}$ | 28.1 $^{NS}$ | 2.03$^{†}$ b | 272 $^{NS}$ | 22.4 $^{NS}$ | 234 $^{NS}$ | 18.7 $^{NS}$ |
| | 22 | 7758 | 33.2 | 2.81 | 28.7 | 2.14 ab | 257 | 22.0 | 225 | 16.6 |
| | 45 | 8594 | 32.1 | 2.67 | 29.3 | 2.19 a | 276 | 22.8 | 248 | 18.7 |
| | 67 | 9088 | 32.4 | 2.77 | 28.9 | 2.28 a | 295 | 25.1 | 265 | 20.8 |
| | 90 | 8644 | 32.1 | 2.72 | 27.4 | 2.15 ab | 274 | 23.3 | 233 | 18.5 |
| | *Mean* | 8490 | 32.5 | 2.73 | 28.5 | 2.16 | 275 | 23.1 | 241 | 18.6 |
| | *CV* | 17.2 | 7.55 | 10.2 | 5.88 | 4.37 | 16.8 | 13.9 | 14.6 | 17.0 |
| 2019 | 0 | 6208 $^{NS}$ | 32.0 $^{NS}$ | 3.32 $^{NS}$ | 29.0 $^{NS}$ | 1.70 $^{NS}$ | 201 $^{NS}$ | 24.2 a | 203 $^{NS}$ | 12.4 a |
| | 22 | 6662 | 32.5 | 3.21 | 30.3 | 1.61 | 217 | 21.7 b | 201 | 10.8 ab |
| | 45 | 6062 | 30.4 | 3.00 | 29.9 | 1.67 | 185 | 18.0 c | 180 | 9.58 b |
| | 67 | 6360 | 32.0 | 3.04 | 29.7 | 1.61 | 204 | 19.3 bc | 189 | 10.3 b |
| | 90 | 6290 | 31.5 | 3.07 | 29.9 | 1.54 | 198 | 18.7 bc | 183 | 9.57 b |
| | *Mean* | 6316 | 31.7 | 3.1 | 29.7 | 1.6 | 201 | 20.1 | 190 | 10.4 |
| | *CV* | 11.5 | 5.65 | 13.1 | 9.67 | 7.51 | 12.5 | 8.02 | 8.89 | 8.93 |

$^{NS}$ = Not significant at P = 0.05

$^{†}$ = Significant at P=0.1

Table 2. Analysis of Variance and treatment means of soybean grain yield, test weight, moisture, plant stand, and 100 seed weight by 5 rye seeding rate treatments located at the Southeast Research Farm near Beresford, SD, 2018-2019.

| Sample Date | Seeding Rate | Yield | Test Weight | Moisture | Plant Stand | 100 seed weight |
|---|---|---|---|---|---|---|
| | kg ha$^{-1}$ | Mg ha$^{-1}$ | Kg m$^{-3}$ | % | plants ha$^{-1}$ | g |
| 2018 | 0 | 4.65 ab | 621 $^{NS}$ | 11.9 $^{NS}$ | 374424 $^{NS}$ | 14.9 |
| | 22 | 4.46 c | 632 | 11.9 | 292654 | 16.1 |
| | 45 | 4.50 bc | 591 | 11.4 | 305565 | 15.0 |
| | 67 | 4.49 c | 610 | 11.5 | 292654 | 14.7 |
| | 90 | 4.66 a | 572 | 11.3 | 301261 | 14.6 |
| | *mean* | 4.55 | 605 | 11.6 | 313312 | 15.1 |
| | *CV* | 2.19 | 6.30 | 3.54 | 23.3 | 1.61 |
| 2019 | 0 | 3.70 $^{NS}$ | 697 $^{NS}$ | 9.86 $^{NS}$ | 238140 $^{NS}$ | 15.8 $^{NS}$ |
| | 22 | 3.77 | 694 | 9.55 | 255355 | 15.8 |
| | 45 | 3.76 | 690 | 9.84 | 241009 | 15.9 |
| | 67 | 3.72 | 684 | 9.63 | 301261 | 16.2 |
| | 90 | 3.81 | 612 | 8.67 | 229532 | 16.1 |
| | *mean* | 3.75 | 675 | 9.51 | 253059 | 16.0 |
| | *CV* | 4.26 | 10.7 | 9.71 | 11.5 | 3.08 |

| Source | Yield | Test Weight | Moisture | Plant Stand | 100 seed weight |
|---|---|---|---|---|---|
| | | | Pr>f | | |
| Treatment (Trt) | NS | 0.06 | NS | NS | NS |
| Year | <0.001 | <0.001 | <0.001 | 0.001 | 0.005 |
| Trt*Year | NS | NS | NS | NS | NS |

$^{NS}$ = Not significant at P = 0.05

***Rye Burndown Timing.***

This study was established in both 2018 and 2019; however, the soybean stand in the 2018 study was lost due to flooding that occurred in June of that year. Therefore, only the data from 2019 is discussed here.

In 2019 we see that rye biomass and C:N ratio both increased sharply with later termination during the month of May (Fig. 3). Similar to the seed rate studies, there is a trend for lower levels of S in corn stover with increased levels of rye biomass (Table 3 and Fig. 3); however, later in the season when the rye cover crop is also part of the previous crop residue, it appears that more S is sequestered in stover in the later burndown/high rye biomass plots. Comparing the first and last burndown dates, the difference in the amount of S tied up in crop residues on the August 30th sample date is 1.6 kg S/ha.

Looking at soybean shoot biomass and nutrient content later in the season (Table 4), we see a trend for S concentration and S content to be lower in the later burndown treatments; however, total shoot biomass at R3 was also lower with later rye termination. The plots with heavy rye biomass showed delayed development initially, presumably because of cooler soil temperatures. By the R6 stage differences in shoot biomass were lost and at maturity all the treatments were statistically similar to the control in terms of grain yield (Table 5).

For both the rye seed rate and burndown timing studies, levels of rye biomass greater than 1000 kg/ha were associated with higher levels of S tied up in crop residue later in the season, and a trend for lower S concentration in soybean shoots at the R3 growth stage.

**Sulfur Supplementation.**

Trials looking at use of supplemental S in soybeans following rye were conducted at three sites in 2018 and in 2019. We did not see any significant yield effects at any of the locations (Table 6 and 7).

**Summary and Conclusion**

Studies were done to evaluate the effect of rye seed rate and burndown date on the amount of biomass produced by a rye cover crop and on nutrient status of the following soybean crop.

In this study with trials conducted in the 2018 and 2019 growing seasons (both with cold wet springs), seed rate had a relatively weak effect on rye biomass produced. Timing of cover crop termination had a very strong effect on rye biomass production. Rye typically grows very rapidly in mid to late May and in this study it showed an ability to about triple its biomass (from 930 to 2840 kg/ha) between the 13th and 31st of May. So in terms of determining cover crop biomass, the timing of cover crop termination is a much more important management variable to control than is rye seed rate.

Use of a rye cover crop appeared to accelerate decomposition of the previous year's corn stover. The amount of corn stover at the time of soybean planting was consistently lower in plots that had a rye cover crop with a trend for increased rates of corn breakdown with increasing levels of rye biomass (Fig. 2 and Table 3, first data set). On the other hand, as rye biomass increases it naturally contributes more to residue levels in the following soybean crop. Looking at the data across trials and seasons (which has to be viewed with caution), I would tentatively postulate that there is a "sweet spot" somewhere between 500 and 1000 kg/ha of rye biomass where overall residue levels and nutrient sequestration would be minimized, for those who have that as a goal on their operation. As the rye grows beyond the 1000 kg/ha level, both the amount of residue and the C:N ratio (resistance to decomposition) increase such that more persistent residue is left later in the season. It appears that rye killed before it reaches the 1000 kg/ha is succulent enough that it readily decomposes and does not contribute much to residue levels in the field.

Regarding the magnitude of potential S sequestration by a rye cover crop, where the rye cover crop was allowed to produce 1500 or more kg/ha of biomass, S levels in the residue at the soil surface were 0.7 to 2.5 kg/ha higher towards the end of the season as compared to the control plots. Similarly, the soybean crop at the R3 stage (Table 1 and 4) in these circumstances had 2.1 to 2.8 kg/ha less S relative to that observed in the control plots. Where there is ample S available in the soil, this level of sequestration would not be a limitation, where S availability is marginal, it could contribute to S deficiency.

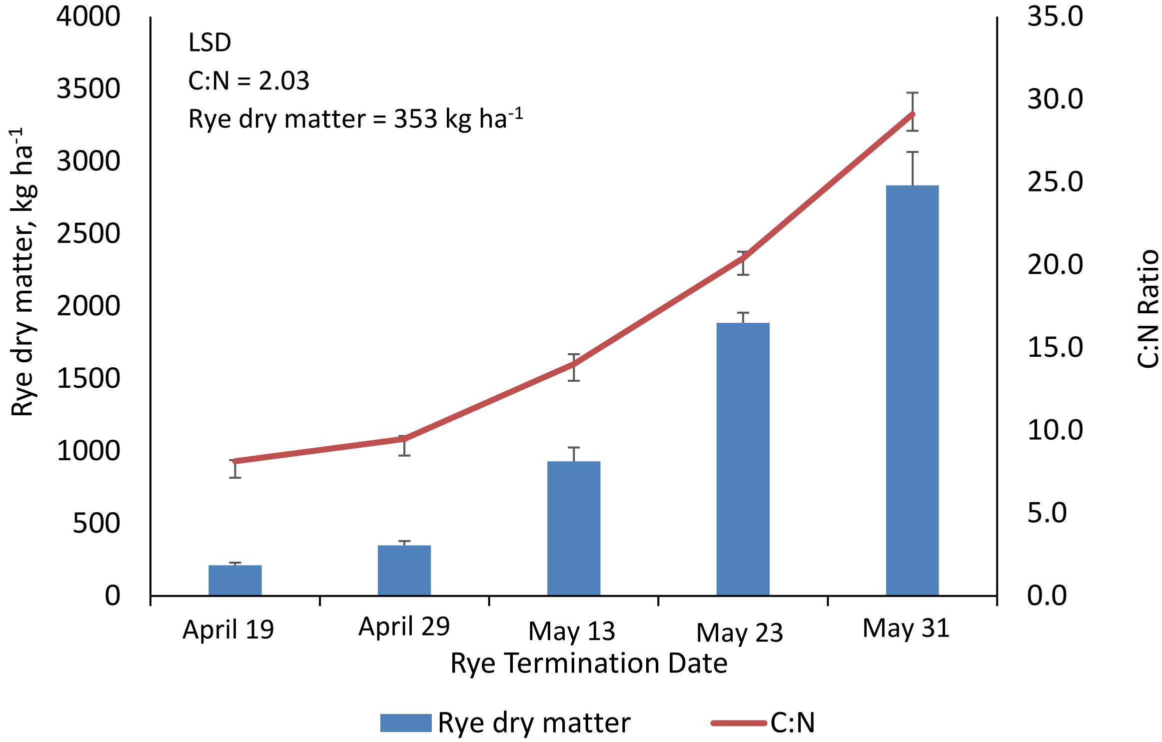



Fig 3. Rye dry matter production and C:N ratio of 5 rye termination dates measured at the time of rye termination located at the SDSU Southeast Research Farm near Beresford, SD, 2019.

Table 3. Nutrient content of previous crop residues on the soil surface for 5 rye termination timing treatments. Samples were taken at the time of cover crop termination, on August 5th corresponding with the soybean R3 growth stage, and on August 30th corresponding with the soybean R6 growth stage located at the Southeast Research Farm near Beresford, SD, 2019.

| Sample Date | Rye Termination | N | P | K | S |
|---|---|---|---|---|---|
| | | ------------------kg ha $^{-1}$ | ---------------- | | |
| Apr 19 | Apr 19 | 27.2 a | 2.68 a | 5.56 a | 2.37 a |
| Apr 29 | Apr 29 | 25.7 a | 2.74 a | 5.94 a | 2.30 a |
| May 13 | May 13 | 27.8 a | 2.91 a | 7.13 a | 2.39 a |
| May 23 | May 23 | 21.0 a | 2.35 a | 5.63 a | 1.82 ab |
| May 31 | May 31 | 12.4 b | 1.38 b | 3.27 b | 1.09 b |
| | *Mean* | 22.8 | 2.41 | 5.51 | 1.99 |
| | *CV* | 25.5 | 27.3 | 26.8 | 28.6 |
| Aug 5 | Apr 19 | 11.6 d | 0.91 d | 2.48 c | 0.82 c |
| | Apr 29 | 12.9 d | 0.91 d | 2.07 c | 0.74 c |
| | May 13 | 20.2 c | 1.69 c | 3.91 c | 1.28 c |
| | May 23 | 33.9 b | 3.78 b | 10.8 b | 2.35 b |
| | May 31 | 45.8 a | 5.70 a | 19.1 a | 3.27 a |
| | *Mean* | 24.9 | 2.60 | 7.68 | 1.70 |
| | *CV* | 16.8 | 21.2 | 29.6 | 25.1 |
| Aug 30 | Apr 19 | 12.9 c | 1.06 c | 3.25 c | 0.89 c |
| | Apr 29 | 12.8 c | 1.02 c | 3.15 c | 0.80 c |
| | May 13 | 17.3 bc | 1.39 c | 3.95 c | 1.14 bc |
| | May 23 | 25.9 b | 2.44 b | 7.61 b | 1.60 b |
| | May 31 | 35.2 a | 3.92 a | 13.8 a | 2.49 a |
| | *Mean* | 20.8 | 1.97 | 6.35 | 1.38 |
| | *CV* | 30.9 | 35.3 | 41.4 | 36.6 |

Table 4. Soybean nutrient concentration and uptake for 5 rye termination timing treatments measured on August 5th at the soybean R3 growth stage, and on August 30th corresponding with the soybean R6 growth stage located at the Southeast Research Farm near Beresford, SD, 2019.

| Sample Date | Rye Termination | Biomass | N | P | K | S | N | P | K | S |
|---|---|---|---|---|---|---|---|---|---|---|
| | | kg ha$^{-1}$ | ------------------g kg$^{-1}$---------------- | | | | --------------------kg ha$^{-1}$----------------- | | | |
| August 5 | April 19 | 6207 a$^{\dagger}$ | 37.1 a | 3.20$^{NS}$ | 22.5$^{NS}$ | 2.17$^{NS}$ | 223 a | 19.8 a | 139 a | 13.5 a |
| | April 29 | 5987 ab | 35.0 b | 3.28 | 22.7 | 2.10 | 211 ab | 19.6 a | 136 ab | 12.7 ab |
| | May 13 | 4920 bc | 35.0 b | 3.11 | 23.8 | 2.07 | 174 bc | 15.6 b | 118 abc | 10.2 c |
| | May 23 | 5432 abc | 34.7 b | 3.22 | 22.6 | 2.10 | 189 abc | 17.5 ab | 123 bc | 11.4 bc |
| | May 31 | 4795 c | 33.8 b | 3.34 | 23.3 | 2.01 | 163 c | 16.1 b | 112 c | 9.69 c |
| | Mean | 5491 | 35.0 | 3.23 | 23.0 | 2.09 | 195 | 17.8 | 126 | 11.5 |
| | CV | 15.2 | 3.63 | 5.81 | 8.97 | 5.13 | 18.2 | 11.8 | 11.0 | 12.7 |
| August 30 | April 19 | 9638$^{NS}$ | 34.5$^{NS}$ | 2.97$^{NS}$ | 17.9$^{NS}$ | 1.88$^{NS}$ | 332$^{NS}$ | 27.2$^{NS}$ | 170$^{NS}$ | 18.1$^{NS}$ |
| | April 29 | 9617 | 34.7 | 2.72 | 16.1 | 1.76 | 333 | 25.6 | 151 | 16.9 |
| | May 13 | 9275 | 34.7 | 2.71 | 17.8 | 1.83 | 322 | 25.3 | 167 | 17.1 |
| | May 23 | 9142 | 35.4 | 2.79 | 18.6 | 1.85 | 323 | 25.5 | 170 | 17.0 |
| | May 31 | 9136 | 34.9 | 2.73 | 17.3 | 1.69 | 319 | 25.0 | 158 | 15.4 |
| | Mean | 9361 | 34.9 | 2.77 | 17.5 | 1.80 | 326 | 25.7 | 163 | 16.9 |
| | CV | 22.1 | 2.03 | 6.27 | 10.6 | 6.43 | 22.2 | 21.5 | 19.2 | 21.2 |

$^{NS}$ = Not significant at P = 0.05

$^{\dagger}$ = Significant at P=0.1

Table 5. Soybean yield, test weight, moisture, 100 seed weight, plant stand and grain nutrient concentrations for 5 rye termination timing treatments measured at harvest on October 18 located at the Southeast Research Farm near Beresford, SD, 2019.
$^{NS}$ = Not significant at P = 0.05

| Sample Date | Rye Termination | Yield | Test Weight | Moisture | 100 seed weight | Plant Stand | Plant Height | N | P | K | S |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $Mg\ ha^{-1}$ | $kg\ m^{-3}$ | % | g | plants $ha^{-1}$ | cm | ---------------------- | ------g $kg^{-1}$------ | ---------------------- | |
| Oct 18 | Apr 19 | 4.77 ab$^{\dagger}$ | 758 b | 11.6 $^{NS}$ | 758 $^{NS}$ | 289211 $^{NS}$ | 85.3 a | 63.2 c | 5.00 b | 17.1 b | 2.92 $^{NS}$ |
| | Apr 29 | 4.50 b | 757 b | 11.6 | 757 | 321345 | 85.0 a | 63.5 bc | 5.10 b | 17.2 b | 2.96 |
| | May 13 | 4.53 b | 764 a | 11.8 | 764 | 325936 | 85.2 a | 63.6 abc | 5.13 b | 17.6 b | 2.97 |
| | May 23 | 4.53 b | 761 ab | 11.7 | 761 | 261667 | 82.7 ab | 64.2 ab | 5.22 b | 17.9 ab | 3.05 |
| | May 31 | 4.91 a | 765 a | 11.7 | 765 | 243304 | 81.1 b | 64.4 a | 5.45 a | 18.5 a | 3.05 |
| | *Mean* | 4.65 | 761 | 11.7 | 761 | 288293 | 83.9 | 63.8 | 5.19 | 17.6783 | 2.99 |
| | *CV* | 5.58 | 0.56 | 1.97 | 0.56 | 29.1 | 2.81 | 0.91 | 3.14 | 3.01 | 4.03 |

$^{\dagger}$ = Significant at P=0.1

Table 6.

Effects of soybean yield and seed nutrient composition with nitrogen and sulfur applications following a rye cover crop. 6 treatments and a control of no fertilizer were used at 3 locations in 2018

| Location | Treatment | Yield | Test Weigt | N | P | K | S | Mg | Zn | Mn | N:S Ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | bu/ac | lb/bu | ---------------------------------- | | -g/kg- | -------------------------------- | | ---------mg/kg--------- | | |
| SERF | Control | 56.0 | 50.0 | 62.7 | 5.86 | 19.3 | 3.05 c | 2.66 c | 37.8 | 32.5 | 20.6 |
| | Mg SO4 10* | 57.1 | 51.1 | 63.2 | 6.39 | 20.5 | 3.10 bc | 2.78 a | 36.3 | 34.8 | 20.0 |
| | Mg SO4 20 | 56.6 | 50.9 | 63.9 | 6.37 | 20.0 | 3.22 a | 2.69 bc | 37.3 | 33.0 | 19.8 |
| | AS 20 | 52.1 | 50.6 | 63.4 | 6.24 | 19.7 | 3.18 ab | 2.69 bc | 35.5 | 34.3 | 19.9 |
| | AS 10 | 55.8 | 47.9 | 63.7 | 6.25 | 20.1 | 3.17 ab | 2.75 ab | 35.5 | 32.8 | 20.1 |
| | Urea 10 | 60.9 | 50.3 | 63.7 | 6.04 | 19.5 | 3.05 c | 2.73 abc | 35.8 | 32.3 | 20.9 |
| | Urea 20 | 61.0 | 49.8 | 63.1 | 6.27 | 20.0 | 3.10 bc | 2.74 abc | 35.5 | 31.3 | 20.4 |
| | *Mean* | 56.8 | 50.1 | 63.4 | 6.20 | 19.9 | 3.13 | 2.72 | 36.2 | 33.0 | 20.2 |
| | *LSD* | NS | NS | NS | NS | NS | 0.118 | 0.0801 | NS | NS | NS |
| Christensen | Control | 62.3 | 53.6 | 62.9 | 5.80 | 18.9 | 3.03 c | 2.91 ab | 37.5 c | 34.5 | 20.0 a |
| | Mg SO4 10 | 67.3 | 53.5 | 63.1 | 5.74 | 18.8 | 3.33 ab | 2.87 bc | 40.25 ab | 36.3 | 19.0 b |
| | Mg SO4 20 | 64.0 | 54.7 | 63.2 | 5.89 | 18.9 | 3.38 a | 2.84 c | 41.5 a | 37.5 | 18.7 b |
| | AS 10 | 64.7 | 52.1 | 63.2 | 5.84 | 18.9 | 3.34 ab | 2.87 bc | 40.8 a | 37.5 | 18.9 b |
| | AS 20 | 65.1 | 53.9 | 62.6 | 5.83 | 19.0 | 3.41 a | 2.87 bc | 41.5 a | 38.3 | 18.3 b |
| | Urea 10 | 65.3 | 53.5 | 63.2 | 5.70 | 18.5 | 3.19 bc | 2.84 c | 38 bc | 35.0 | 19.9 a |
| | Urea 20 | 66.3 | 53.3 | 62.9 | 5.83 | 19.1 | 3.17 bc | 2.94 a | 40 ab | 37.5 | 19.9 a |
| | *Mean* | 64.3 | 53.5 | 63.0 | 5.80 | 18.8 | 3.26 | 2.88 | 39.9 | 36.6 | 19.4 |
| | *LSD* | NS | NS | NS | NS | NS | 0.300 | 0.06 | 2.46 | NS | 1.3 |
| Tornberg | Control | 55.3 | 51.5 | 60.7 | 5.73 | 18.4 | 3.23 | 2.64 | 33.3 | 29.0 | 18.8 |
| | Mg SO4 10 | 55.6 | 52.5 | 60.7 | 5.50 | 18.1 | 3.21 | 2.61 | 33.3 | 28.5 | 18.9 |
| | Mg SO4 20 | 57.5 | 52.2 | 61.3 | 5.73 | 18.5 | 3.28 | 2.63 | 33.8 | 29.0 | 18.7 |
| | AS 10 | 58.3 | 51.5 | 61.3 | 5.59 | 18.3 | 3.23 | 2.61 | 32.5 | 28.3 | 19.0 |
| | AS 20 | 57.4 | 52.6 | 60.7 | 5.68 | 18.4 | 3.27 | 2.63 | 34.0 | 29.5 | 18.6 |
| | Urea 10 | 57.8 | 52.3 | 61.0 | 5.80 | 18.7 | 3.29 | 2.71 | 33.3 | 28.5 | 18.6 |
| | Urea 20 | 59.1 | 52.1 | 60.7 | 5.75 | 18.8 | 3.23 | 2.64 | 33.8 | 28.8 | 18.8 |
| | *Mean* | 57.3 | 52.1 | 60.9 | 5.68 | 18.4 | 3.25 | 2.64 | 33.4 | 28.8 | 18.8 |
| | *LSD* | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| | *F-Test Probability* | | | | | | | | | | |
| | *Location* | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| | *Treatment* | NS | 0.0217 | NS | NS | NS | <0.01 | NS | <0.01 | 0.0488 | <0.01 |
| | *Location x Trt* | NS | NS | NS | NS | NS | 0.0413 | <0.01 | 0.0158 | 0.0873 | 0.0601 |

**Each treatment applied at 10 and 20 lb/ac of S. Urea rates were determined using an equivalent N rate for the N applied in the AS treatments.*

Table 7: Soybean yield results at 3 locations in 2019 in trials looking at soybean yield response to supplemental S application where rye was used as a cover crop.

Nitrogen and Sulfur application following a rye cover crop at locations in 2019

| Treatments | Yankton | SERF | Arlington Rye* | Arlington No Rye* |
|---|---|---|---|---|
| | -------------------- | --------(bu/ac)-------- | -------------------- | |
| Control | 59.9 | 73.3 | 57.6 | 61.0 |
| $K_2Mg_2(SO_4)_3$ 10** | 59.1 | 69.3 | 61.6 | 63.5 |
| $K_2Mg_2(SO_4)_3$ 20 | 61.0 | 71.7 | 61.8 | 62.6 |
| AS 10 | 60.7 | 70.7 | 60.3 | 64.7 |
| AS 20 | 59.7 | 67.9 | 59.1 | 66.4 |
| Urea 10 | 61.4 | 65.8 | 61.3 | 66.6 |
| Urea 20 | 59.3 | 70.4 | 62.4 | 63.5 |
| *Mean* | 60.2 | 69.9 | 60.6 | 64.0 |
| *CV* | 5.04 | 6.88 | 4.87 | 6.56 |
| *LSD* | NS | NS | NS | NS |

**At the Arlington location, plots were set up in areas with and without a rye cover crop.*

***Each treatment applied at 10 and 20 lb/ac of S. Urea rates were determined using an equivalent N rate for the N applied in the AS treatments.*