Midwest Cover Crops Council Report 2021- South Dakota
Prepared by: David Karki

Project Title: The Rye (Secale cereale) Cover Crop Decreased N2O-N Emissions During Early Spring.
PI: David Clay, SDSU

Cover crops can have near opposite effects on soil inorganic N and moisture contents during their growth and decomposition phases, which can impact greenhouse gas (GHG) emissions. Despite differences between growth stages, few greenhouse gas (GHG) studies have separated these phases from each other. This study's hypothesis was that a living cover crop reduces soil inorganic N concentrations and soil water, thereby reducing N_2O emissions. We quantified the effects of a fall-planted living cereal rye (*Secale cereale*) cover crop (2017, 2018, 2019) on the following spring's soil temperature, soil water, water filled porosity (WFP), inorganic N, and GHG (N_2O-N and CO_2-C) emissions and compared these measurements to bare soil. The experimental design was a randomized block, where years were treated as blocks. Rye was fall planted in 2017, 2018, and 2019 and in the following spring. GHG emissions were near-continuously measured from early spring through June. Rye biomass was 1049, 428, and 2647 in 2018, 2019, and 2020 kg ha^{-1}, respectively. Rye reduced WFP in the surface 5 cm by 29, 15, and 26% in 2018, 2019, and 2020. In 2019 and 2020 rye reduced soil NO_3-N in surface 30 cm by 53% in 2019 ($p = 0.04$) and 65% in 2020 ($p=0.07$), respectively. Rye changed the N_2O and CO_2 frequency emission signatures, and prior to calculated corn (*Zea mays*) emergence (VE), it reduced N_2O emissions 66% and did not influence CO_2-C emissions. After VE, rye and bare soils N_2O emissions were similar. These results suggest that to more precisely assess the influence of cover crops on seasonal N_2O-N emissions, sampling protocols must account for early season impacts of the living cover.

Project Title: Crop yield and economics of cropping systems involving different rotations, tillage, and cover crops
PI: Sandeep Kumar, SDSU

Diversified cropping systems integrated with winter cover crops and no-till (NT) system can provide substantial soil conservation benefits in the Midwest Corn Belt of the United States, but there is uncertainty on how these practices affect producer profits. This study compared crop yield and economic performance from cropping systems that featured three crop rotations— corn (*Zea mays* L.)-soybean (*Glycine max* [L.] Merr.; 2-yr), corn-soybean-oat (*Avena sativa* L.; 3-yr), and corn-soybean-oat-winter wheat (*Triticum aestivum* [L.]; 4-yr); two tillage systems—NT and conventional-till (CT); and two cover cropping managements—cover crop (CC) and no-cover crop (NC). Tillage and rotation treatments were established in 1991, whereas cover cropping was introduced in 2013, so data from 2014 through 2018 was used for the yield and economic comparisons. Over the study period, the NT system reduced the corn yield across all rotations but increased the soybean yield under 2-yr rotation as compared to the CT system. Hence, both tillage systems were economically equivalent, whereby NT system improved benefit-cost ratio as compared to the CT system. In our study, while CC in its short-term did not contribute to yield and overall economic benefits, but we observed highest gross revenue and second best net returns from 2-yr-CC plots under the NT system as compared to all other cropping systems. When compared to 2-yr rotations, diverse crop rotations (3- and 4-yr) increased the corn and soybean yields and associated profits; yet compromised overall profitability due to the lower profits of small grains. Therefore, it is important to identify other profitable crops to diversify the corn-soybean rotations that are beneficial for soils and the environment.

Project Title: Cover Crop Nutrient Cycling (CCNC) Project Research Report 2020

South East Research Farm, Beresford

PI: Anthony Bly, SDSU

Introduction

Cover crops are essential in 'catch and release' of nutrients in the agricultural production systems. Other than cycling nutrients through their biomass, cover crops also regulate water availability to the cash crops. We hypothesized that cover crops would help in saving mobile nutrients and would provide optimum moisture condition for cash crop production. We also theorized that different cover crop mixes alone or in combination with different nitrogen (N) rates would influence cash crop production differently and we intended to determine the interactions among cover crop species and N rates.

Material and methods

Two experiments were laid out side by side in the 'plot 121' (43.040, -96.900) of the South East Research Farm, Beresford SD. Cover crops were grown in the fall 2019 and corn was grown in the summer of 2020. In one of the experiments, a cover crop mix was grown in a 60ft by 60ft plot where four 15ft by 30ft plots were sprayed out to kill the cover crops, and left cover crops growing in the plots side by side, following a randomized design. In the other experiment, 3 different cover crop mixes, grass mix (90% grass spp., 10% broadleaf spp.), broadleaf mix (90% broadleaf spp., 10% grass spp.), and 50/50 mix (50% grass spp., 50% broadleaf spp.), were tested with a no cover crop control. The cover crops were winterkilled, and corn was grown in those plots in the following summer, with 6 different N rates, 0, 40, 80, 120, 160, 200 lbs./a N (Super-U). Cover crop plots were 30ft by 90ft in dimension in fall and each plots were divided in six 30ft by 15ft plots for N rate treatments in the summer.

8 Cover	6 No Cover	4 No Cover	2 Cover
7 No Cover	5 Cover	3 Cover	1 No Cover

Figure 1. *Lay out of the experiment comparing corn yield with and without cover crop*

Replication 1

Check 4	40	120	200	160	80	0
Broadleaf 3	120	0	40	200	160	80
50/50 2	80	200	120	160	0	40
Grass 1	160	40	80	0	120	200

Turn Alley 50 feet

Replication 2

Broadleaf 8	0	40	80	120	160	200
Check 7	200	40	120	160	0	80
Grass 6	120	0	200	80	40	160
50/50 5	80	120	160	0	200	40

Figure 2: *Experimental layout to test different cover crop mixes and nitrogen rate interactions; The numbers in the cells indicate the nitrogen rate in lbs./a*

Result and Discussion

We found that cover crop did not reduce corn yield and mean corn yield under cover crop mix was higher (181.1 ± 42 Bu/a) than corn yield under no cover (169.7 ± 29 Bu/a) treatment (table 1). Our observation was similar to previous literatures (Bergström and Jokela, 2001). One of the possible reasons might be higher amounts of available nutrients during cash crop growing season in the cover crop plots, while in the plots without cover crops, mobile nutrients leached out of soil profile due to lack of living roots during previous fall and inadequate biomass cover.

Table 1. *Mean Corn Yield Values under plots with and without cover crops at Southeast Research Farm, Beresford in 2020*

Cover Crop Treatment	Yield (Bu/a)
Cover	181.1±42
No Cover	169.7±29

Table 2. *Mean Corn Yield Values under plots with three different cover crop mixes, grass, broadleaf, and 50/5 mixes, in combination with six different nitrogen rates at Southeast Research Farm, Beresford in 2020*

Nitrogen Rate (lbs./a)	Yield (Bu/a)			
	Grass Mix	Broadleaf Mix	50/50 Mix	Control
0	78.52±7.3	69.95±5.2	79.84±4.1	108.4±11
40	101.4±10	106.5±9.5	107.1±12	140.3±11
80	127.0±8.5	128.5±9.5	122.3±7.4	142.7±12
120	144.8±19	153.7±6.8	131.6±15	148.3±5.6
160	134.4±15	144.3±5.0	125.8±6.1	158.4±23
200	130.6±34	143.9±15	145.7±6.7	157.6±13

Among three cover crop mixes, broadleaf mix had lowest corn yield (69.95 ± 5.2 Bu/a), while grass (78.52 ± 7.3 Bu/a) and 50/50 (79.84 ± 4.1 Bu/a) mix had similar yields, when no N fertilizer was added (table 2). However, with addition of N fertilizer, corn yields in 2020 were similar irrespective of cover crop mixes. Above 120 lbs. N /a, yield under grass and broadleaf mix were reduced, but under 50/50 mix, no definite trend was found. Investigating cover crop and N rate interactions, highest corn yield (153.7 ± 6.8 Bu/a) was recorded under broadleaf mix with 120 lbs. N /a. Overall, higher yields were recorded under no cover treatment, except for 120 lbs. N /a treatment. We can speculate that the interactions between different cover crop species and N were complex and multidimensional and there is a knowledge gap still existing in the related scientific community. We are still investigating the possible reasons for these outcomes and will report them in the future.

Conclusion

Our research proved that cover crops did not decrease cash crop yield and proper N fertilization management is necessary to maintain higher yields.

Acknowledgement

This research project is partially support by funding from USDA/NRCS-SD through a grant provided by USGS, the South Dakota Ag. Experiment Station, SDSU Extension and the Southeast Research Farm.

Project Title: Prevent Plant/Burndown Herbicide Residual Effects on Cover Crops
PI: Gared Shaffer, SDSU

Interest in cover crops has dramatically increased across the world due to their many potential benefits. These benefits included building soil organic matter, reducing soil erosion, increasing soil water-holding capacity, producing forage, improving soil microbial biomass, providing biomass for forage and much more. Designing effective herbicide programs while following pesticide label restrictions can be challenging in any cropping system. Rotations that include cash crops and cover crops are complex, and the challenge is increased when a cover crop is needed for ground cover or supplemental livestock forage. There are two primary reasons for label restrictions related to cover crops. First herbicide residues may prevent successful establishment of the cover crops and second, residue tolerances have been established for the presence of herbicide within the following crop. This research could provide producers with better guidelines on the interactions of cover crops and herbicides in Prevent Plant scenarios and burndown scenarios before cover crop planting in South Dakota.
Objective: Establish three burndown herbicide residual effects plots on cover crops in South Dakota during the years of 2020 and 2021.
In 2020, three plot locations where established and information was gathered off of each location. This data will be combined with data gathered in the 2021 growing season at three plot locations in South Dakota. The three locations in 2020 were SE Research Farm near Beresford, SD; NE Research Farm near South Shore, SD; and Sturgis Research Farm near Sturgis, SD. The same locations are planned for 2021.

Project Title: Inter-seeded Cover Crops Influence on Corn Nitrogen Fertilizer Needs, Corn Yield, and Soil-Nitrogen
PI: Jason Clark, SDSU

Moving from conventional to no-till with the inclusion of cover crops can improve soil organic matter, soil structure, and water and nutrient holding capacity that may reduce environmental degradation from the loss of fertilizers and improve crop yield. Cover crops can be inter-seeded directly into standing corn with a high clearance planter. This innovative method of planting cover crops lowers seeding rate requirements and increases the time cover crops are growing and taking up excess nutrients and water. Inter-seeding cover crops may change the amount and timing of nitrogen (N) provided to the crop from decomposition (mineralization), which may increase or decrease needed N fertilizer to optimize corn grain yield. The objectives of this project were to 1) compare the effect of inter-seeded cover crop mixtures on corn production and post-harvest soil-N content.

In 2020, corn was planted into 2019's soybean field where cover crops were inter-seeded the previous year. Cover crop treatments were inter-seeded for corn at the V5–V6 corn growth stage. Cover crop treatments were: 1) no cover crop, 2) single grass species (annual rye grass), and 3), grass/broadleaf mixture (annual rye grass, crimson clover, turnip, and radish). Six nitrogen rates from 0–250 lbs ac^{-1} in 50 lb increments were applied near planting.

At our southeastern South Dakota site, the grass/broadleaf mixture had a much higher optimal N rate (250 lbs ac^{-1}) due to its continuously linear relationship with N rate compared to no cover crop (42 lbs ac^{-1}) and grass cover crop (66 lbs ac^{-1}) treatments. At the optimal N rates of the grass and no cover crop treatments, the grass/broadleaf treatment yielded between 20 to 30 bu ac^{-1} less. Similarly at our east central South Dakota site, the grass/broadleaf mixture yielded similar to the no cover and grass cover crops, but required 70 lbs N ac^{-1} more to achieve optimal yield. At the optimal N rates of the no cover and grass cover crop treatments the yield from the grass/broadleaf mixture was between 20 to 30 bu ac^{-1} less. These results indicate in the first two years of inter-seeding cover crops that a grass/broadleaf mixture may require additional N to obtain optimal yield while an inter-seeded grass cover crop may not. This project will be on-going to enable us to determine the long-term effects of interseeding different cover crop mixtures into a corn-soybean rotation.

Project Title: Observation of the Effects of Winter Annual versus Summer Annual Cover Crops with Different Spring Herbicide Treatments on Corn Yield

PI: Peter Sexton

In a corn/soybean/small grain rotation there is an opportunity to raise cover crops after small grain harvest and ahead of the corn crop. There are many facets to the question of what cover crops to raise and the most advantageous ways to manage them. Previous work at the Southeast Research Farm suggests that in the absence of grazing, corn does better after a cool-season broadleaf blend (brassicas and legumes) than after a grass-based blend. Besides the question of broadleaves versus grasses, there is also the question of whether to select winter annuals such as rye and hairy vetch which will survive and grow in the following spring, versus summer annuals such as radishes and oats that will usually winter kill. This study was conducted to gather data comparing use of summer annuals (radish only, and also a blend of summer annuals) versus use of a winter rye/hairy vetch cover crop. We also included a treatment where the blends were banded two rows of the rye/vetch blend followed by two rows of the radishes on a 7.5" row width. Four different spring weed control treatments were also evaluated with the different cover crop treatments.

METHODS

The study was conducted at the Southeast Research Farm with the previous crop being oats. Cover crop plots were planted in 15' wide plots 400' long on 23 August, 2019, with five replications in a randomized complete block design. Cover crop treatments were as follows:

CC	Treatment
1	Control (no cover crop)
2	Cool-season broadleaf mix (16 lb/a)
3	rye:vetch- 20:14 lb/a each- 34 lb/a rate
4	radish (8 lb/a)
5	rye:vetch & radish in bands (paired alternative rows)

The cool-season broadleaf mix (treatment 2) consisted of the following mix:

Species	Full seedrate (lb/a)	PercentMix (%)	Per Acre Rate in Mix lb/a)
Radish	8	27.6	2.21
Turnip	4	21.2	0.85
Dwarf Essex	5	15.3	0.76
F. Sorghum	15	7.9	1.19
Pea	70	7.3	5.1
Flax	30	5.7	1.7
Sorg/sudan	20	4.7	0.93
C. Vetch	25	2.7	0.68
Winfred Brassica	5	2	0.1
Kale	5	1.7	0.08
Barley	50	1.4	0.68
Oat	70	1	0.68
Buckwheat	45	0.8	0.34
Cowpea	30	0.6	0.17
Fava Bean	70	0.2	0.17

In the spring of 2020, the following herbicide treatments were applied perpendicularly to the cover crop plots (strip-split plot design), with each strip 30' wide and replicated 3 times.

Treatment	
1	Mowed at time of corn emergence
2	Glyphosate only (32 oz/a)
3	Glyphosate, metolachlor, metribuzin, saflufenacil
4	Glyphosate, metolachlor, metribuzin, saflufenacil, 2,4-D

All plots were fertilized with 80 lbs/ac of N as urea on April 7 with another 58 lbs of N/ac sidedressed as UAN on June 12. The whole field received a post-emergence application of glyphosate on June 11 and atrazine (0.4 lb/ac) with mesotrione (3 oz/ac) on 19 June, 2020. At harvest maturity, the inner two rows of each plot were harvested with a Zurn small plot combine. Data were initially analyzed as a split plot design (cover crop as the main plot and herbicide as the subplot); because of cover crop by herbicide interactions ($P < 0.10$), the two factors were then analyzed separately (cover crops within herbicide treatments and vice versa).

RESULTS and DISCUSSION

Both cover crop and herbicide main effects were statistically significant despite the presence of cover crop by herbicide interactions (Table 1). Among the cover crops, the radish treatment gave the highest yields in the following corn crop. This was followed by the control and broadleaf mix treatments which provided similar yields, with the winter annual materials (rye and hairy vetch) giving the lowest yields among the cover crops tested. The banded treatment with winter annuals (corn being planted in the radish rows between the rye:vetch bands) were numerically 5 bu/ac higher than where the winter annuals were planted in a blend across the whole area. When cover crop treatments were analyzed within herbicide treatments, the same trends held true. For each of the four herbicide treatments, corn following a radish cover crop showed the highest numeric yield, and the rye:vetch blends tended to show lower yields (Table 3). The broadleaf mix tended to yield similar to the control, except in the treatment that included 2,4-D, which may be an anomaly. The lower yields in the rye:vetch mixture inidicate this type of cover crop needs to be managed differently - perhaps earlier burndown to prevent N sequestion and allelopathic effects, or perhaps more N is required to make the winter annual system successful in our environment. This will have to be the topic of future research.

Comparing the herbicide treatments within each cover crop, the glyphosate-only treatment gave as good or better yields than did the preplant burndown mixture. This field does not have a history of glyphosate resistant weeds, and it has been relatively weed-free in previous seasons. In this situation, glyphosate by itself was adequate for initial weed control. The mowing treatment did particularly poorly with the winter annual cover crop as it allowed for them to regrow and compete with the developing corn crop.

CONCLUSION

In this study, corn showed an 8 bu/ac yield benefit following a radish cover crop relative to the control treatment (no cover crop). Use of a winter annual rye:vetch blend tended to decrease yield of the following corn crop. More research will be needed on management of winter annual cover crops to be able to utilize them without decreasing corn yields in our environment.

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Project Title: Sulfur and Nitrogen Dynamics for Rye Raised as a Cover Crop
PI: Peter Sexton, SDSU

Background

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 (http.s://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 cited above.

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.

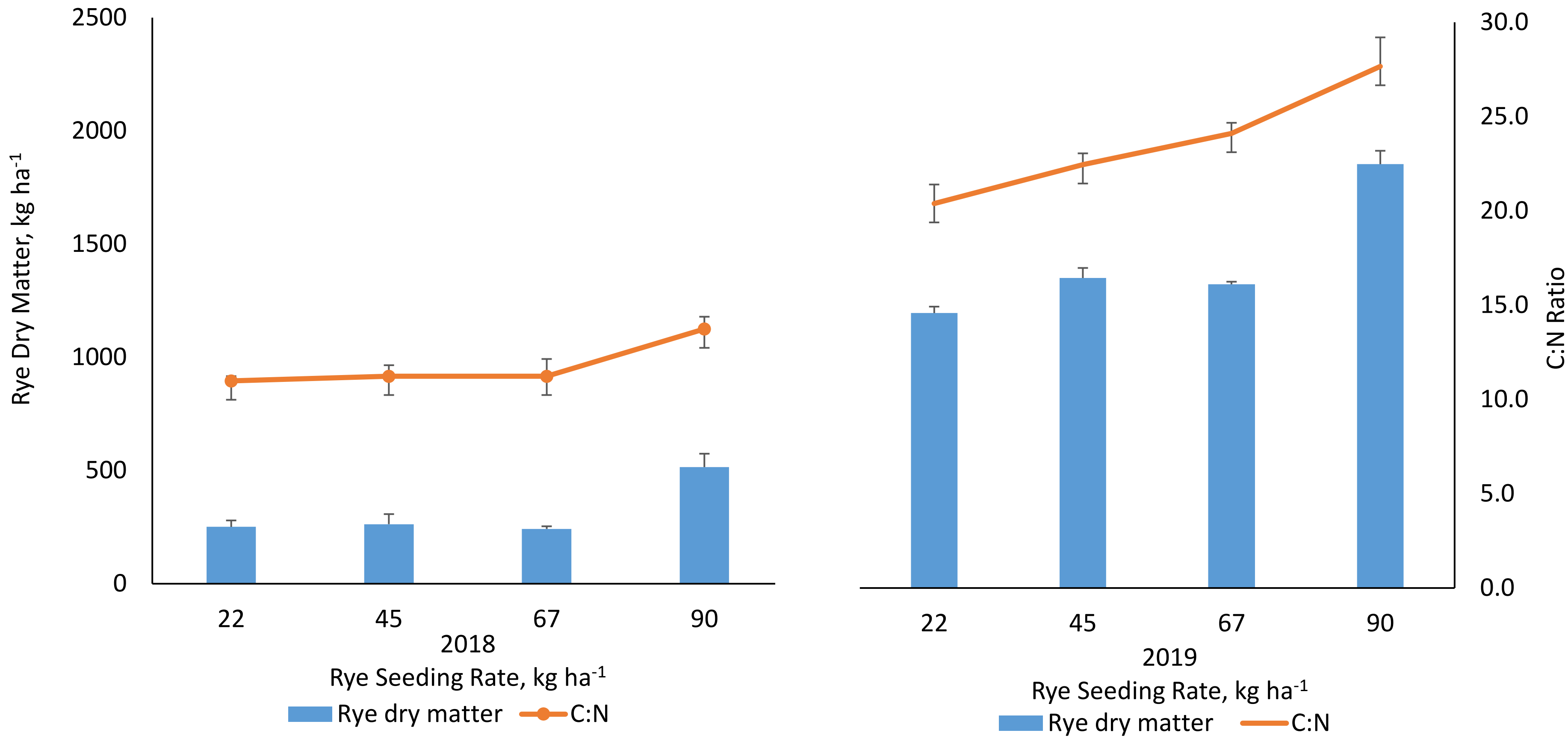

Figure 1. Rye dry matter production and C:N ratio measured at rye termination located at the Southeast Research Farm near Beresford, SD, 2018-2019.

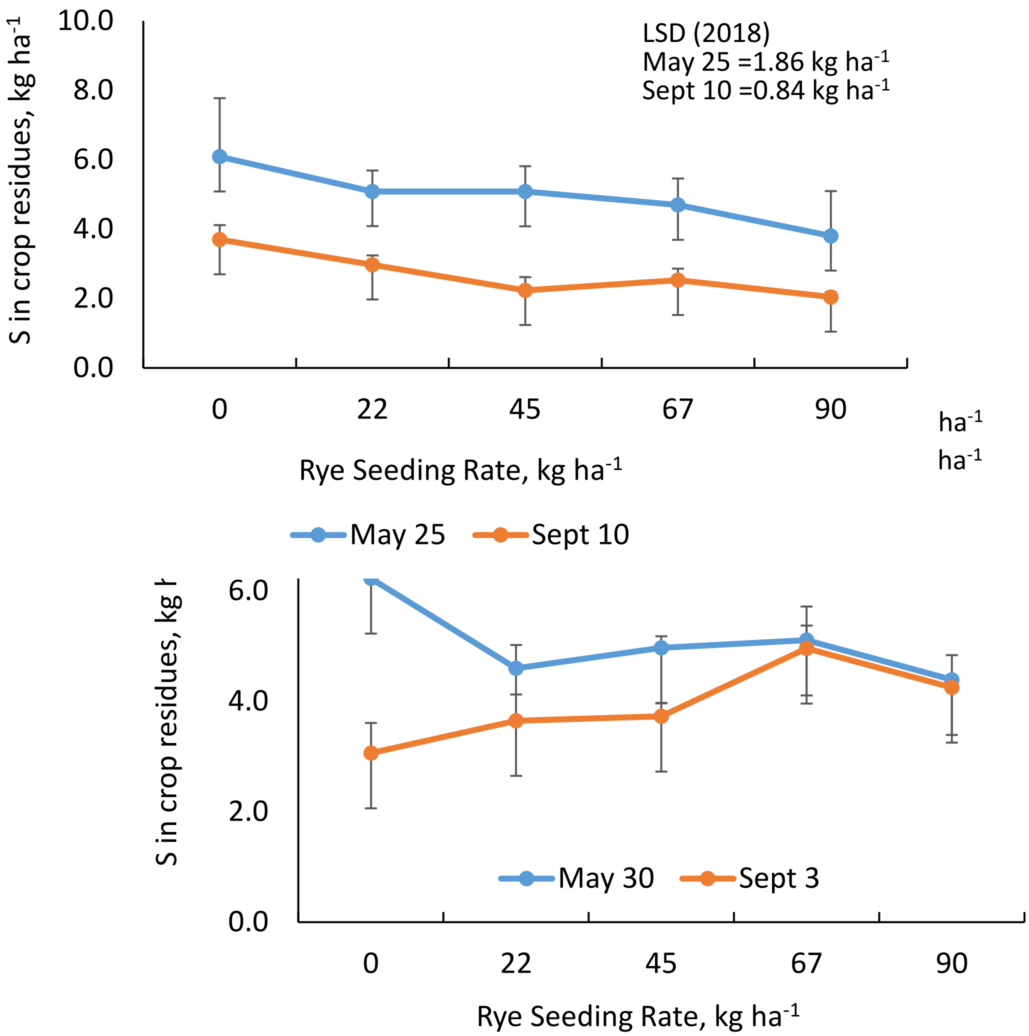

Fig. 2. The amount of S in crop residues versus rye seed rate treatment in studies conducted using rye as a cover crop ahead of soybeans at the Southeast Research Farm in 2018 and 2019. The spring measurement of crop residue includes only corn stover as the rye was living at the time of measurement.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

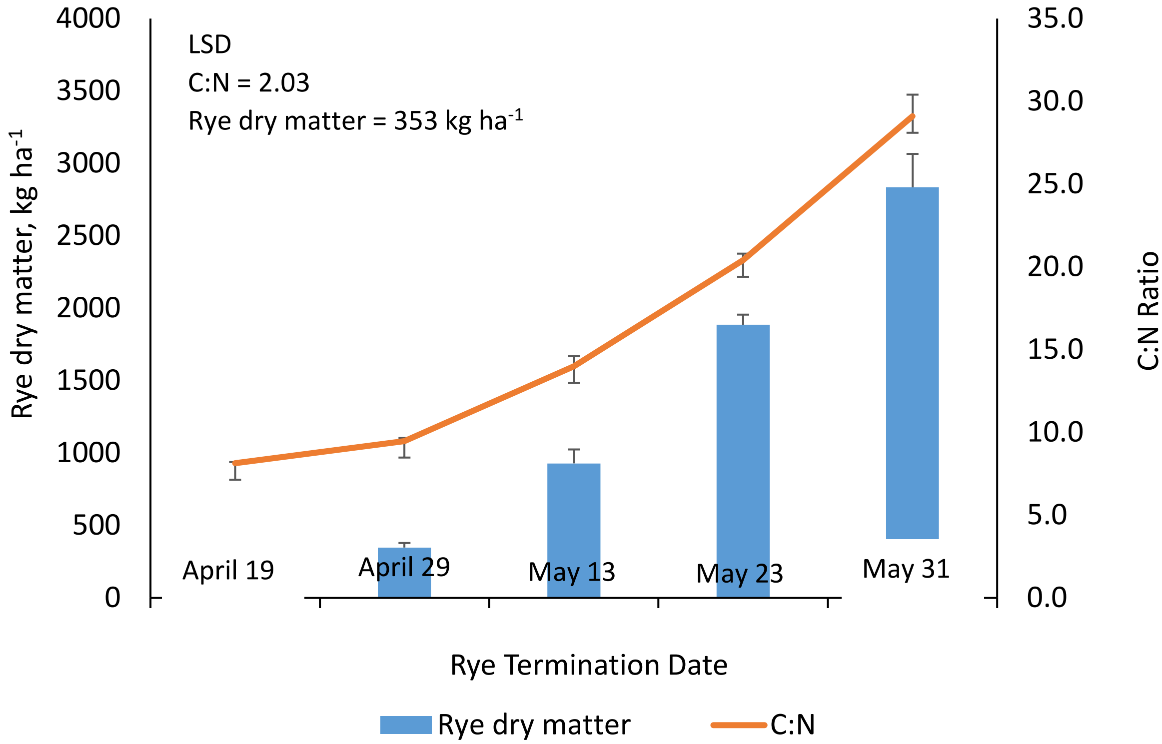

Fig 3. Rye dry matter production and C:N ratio of 5 rye termination dates measured at the time of rye termination located at the SDSU Southeast Research Farm near Beresford, SD, 2019.

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[†]	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

[†] = 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
† = Significant at P=0.1

Sample Date	Rye Termination	Yield	Test Weight	Moisture	100 seed weight	Plant Stand	Plant Height	N	P	K	S
							cm	---------------------g kg^{-1}----------------- --			
		Mg ha^{-1}	kg m^{-3}	%	g	plants ha^{-1}					
Oct 18	Apr 19	4.77 ab†	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

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.*