Minnesota Wheat Research and Promotion Council

Project Title: Enhancing Spring Wheat Yields through Split In-Season Nitrogen and Sulfur Applications in Conventional and No-Till Systems

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Project Period: 2025
Estimated cost: $31,720

Abstract: Accurate management of nitrogen (N) and sulfur (S) is essential for optimizing wheat yields and reducing environmental impact. These nutrients are critical for photosynthesis and chlorophyll production. Excessive N application, common in North Dakota and Minnesota, can be costly and unsustainable. This study, conducted in Carrington, ND (sandy-loam soil) and Staples, MN (sandy soil), evaluated the effects of N and S rates on wheat yield using a randomized complete block design (RCBD) with four replicates. Wheat was planted in late April, with N treatments at 0 (control), 50, 75, 10, and 150 lb acre^{-1}, and S treatments at 0 (control), 10, and 20 lb acre^{-1}. The split application was used on N and S (60% starter and 40% at Feekes 5 stage), with a separate control treatment of 100 lb N acre^{-1} and 22 lb S acre^{-1} applied at planting (110N-20S-PD). **Significant differences were found in the combined analysis across both sites, with sulfur rates increasing wheat yield by 30.5% at equal nitrogen levels. Specifically, the highest split application rates of 150N-20S (56 bu acre^{-1}) and 150N-10S (56 bu acre^{-1}) yielded significantly more than 150N-0S (41 bu acre^{-1}). Additionally, there were no significant differences in yield between treatments 110N-20S-PD (48 bu acre^{-1}) and 75N-20S split (47 bu acre^{-1}), demonstrating that a split application, with 25% less nitrogen, can be as effective as full rate planting date application. Overall, split application of N and S significantly enhanced wheat yields in both locations, suggesting the potential for higher yields with reduced fertilizer use and lower carbon intensity.**

Importance of this project to the profitability of wheat producers:
This research highlights the benefits of split nitrogen (N) and sulfur (S) application in wheat. Early spring soil tests can miss actual N and S availability during the season due to organic matter changes, mineralization, and weather. In-season multispectral data helps determine precise N and S rates, reducing fertilizer waste and improving yields**. Results from 2024 from Carrington and Staples showed that adding sulfur increased wheat yield by 30.5% at the same nitrogen rates. Specifically, using 150 lbs. of N with either 10 or 20 lb. of S per acre yielded about 56 bu acre^{-1}, significantly outperforming the 150N-0S treatment, which yielded 40.9 bu acre^{-1}; please see Figure 1 attached for more details. Additionally, split applications with 25% (75N-20S) less nitrogen matched the effectiveness of full-rate (100N-20S-PD) of single applications, improving nitrogen use efficiency by 7-12% (for more details, see Figure 2 attached). In a 500-acre wheat operation, adding 10 lbs. of S per acre increased income by up to $49,727 (please see Table 1 attached for more details). These results show that sulfur use and split N applications can enhance yield and profit, making wheat production in Minnesota and North Dakota more sustainable and productive.**

Procedures:
Field establishment: The first location will be Carrington, ND, where plots will be located on dryland, no-till loamy soils. The second location will be Central Minnesota Demonstration and Research Irrigation Farm in Staples, MN, where plots will be located on conventional tillage irrigated sandy soils. They will also provide support in field allocation, planting, spraying, and crop updates during the season. The experimental unit will be 25 ft x 12 ft in size.
Spring Wheat MN Rothsay (seeding rate of 2.3 bu acre-1) will be randomized in a complete block design (RCBD) with four replicates in late April 2025. Seventeen treatments will be applied with urea and ammonium sulfate, adding the following N and S nutrient rates (lb acre-1) of 0N-0S, 0N-10S, 0N-20S, 50N-0S, 50N-10S, 50N-20S, 75N-OS, 75N-10S, 75N-20S, 100N-0S, 100N-10S, 100N-20S, 150N-0S, 150N-10S, and 150N-20S. In addition, one treatment with 100N-20S will be applied at the planting date as a control. N and S rates will split 60% as a starter and 40% at wheat Feekes 5 stage.
Plant Sampling: Mid-season biomass samples will be taken from a four-square-foot section of the wheat plot at Feekes 5 stage. These samples will be weighed and tested for nitrogen (N) and sulfur (S) content. The sulfur-to-nitrogen ratio will indicate sulfur sufficiency in the plant tissue. Wheat biomass will be retaken close to harvest from a four-square-foot section, and these samples will be weighed but not analyzed. Each plot will be harvested to determine grain yield, test weight, and protein content.
Soil sampling: Composite samples will be taken at 0-6- and 6-24-inches depth in early spring for NO3-N soil pH,

P, K, Sulfate-S, Zinc, pH, and organic matter, and samples taken at 6-24 inches will be tested for NO3-N and Sulfate-S. These samples will be used to determine the N and S recommendations. In-season soil sampling will be done in wheat at Feekes 5 stage, testing for NO3-N and Sulfate-S. After harvest, samples will be collected at 0-24 inches depth, testing for NO3-N and Sulfate-S.

Multispectral wheat canopy data:

The Greenseeker hand-held sensor will collect NDVI in each plot at Feekes stages 3, 5, and 10.5 of the wheat stages.

A drone DJI Phantom 4 MicaSense Red-Edge multispectral camera will collect canopy reflectance images at 550, 670, 715, and 840 (green, red, red-edge, and near-infrared). Data collection will be at Feekes stages 3, 5, and 10.5 of the wheat stages. Once images are obtained, several vegetation spectral indexes (VIs) will be calculated using MATLAB 2023b.

Weather and soil data: Daily temperature (min and max), relative humidity, and rainfall will be obtained from the NDAWN weather station in North Dakota. Soil moisture and temperature will be obtained from check plots with a Decagon 5TM soil moisture sensor (3,6, and 12-inch depth), and reads will be recorded daily with a Decagon EM50 datalogger.

Statistical analysis will be conducted using standard procedures for a randomized complete block design (RCBD). The variance analysis was performed using the MIXED procedure of SAS 9.4 for all variables above. A mean separation test will be performed using the least significant difference (LSD) ($P \leq 0.05$).

Outline the timeline for completion: This research will be performed during the wheat growing season in 2025.

Research Finding dissemination methods: This research project acknowledged Minnesota Wheat Research and Promotion Council support, and results were published at:

- NDSU All Ag Conference, poster: Enhancing Spring Wheat Yields through Split In-Season Nitrogen and Sulfur Applications in Conventional and No-Till Systems. Fargo, ND, 11/06/2024
- All Innovations for Changing Climate, ASA, CSSA, SSA International Annual Meeting. An oral presentation titled Enhancing Spring Wheat Yields through Split In-Season Nitrogen and Sulfur Applications in Combination with RGB Smartphone Images and NDVI-Based Yield Prediction Models. San Antonio, TX, 11/13/2024.
- Annual Reports Carrington Research Extension Center, NDSU. Extension publication titled: Split In-Season Nitrogen and Sulfur Applications Increase Spring Yield and Quality in Conventional and No-Till Systems. It will be published in December 2024.

We will keep a similar outreach plan for the following season, adding results to NDSU field days.

Estimate the budget requirements: Partial salary support is requested for a research specialist and research technicians to plant, maintain and harvest the trials and for part time staff to collect optical sensor data and help with trial maintenance and data collection. Fringe benefits are calculated at 60% for research specialist, 66% for technical staff, and 10% for part time staff. Repairs are for repairs to the equipment used to complete the project including tractors, planters, and combines. Operating fees are for soil sample and plant analyses. Materials and supplies are for fuel, fertilizer, chemical, plot stakes and supplies, and laboratory supplies. Travel funds are for travel to and from the trial areas during the growing season and to acquire supplies. Travel to the Minnesota site includes mileage, hotel, and per diem for trips to collect soil samples, trips for sensor data collection, and harvest. Other direct costs are lab fees for soil sample analyses and plant analyses for both locations (composite soil sample 2 sample x $35/sample = $70; soil N and S 384 samples x $17.70/sample = $6,796; Biomass N and S 128 samples x $33.9/sample = $4,338) and a contracted services agreement ($1,470) to Central Minnesota Demonstration and Research Farm in Staples for providing the test site.

References:

Andrews, M., J.A. Raven, and P.J. Lea. 2013. Do plants need nitrate? The mechanisms by which nitrogen form affects plants: Do plants need nitrate? Annals of applied biology 163(2): 174–199. doi: 10.1111/aab.12045.

Franzen, D.W., L.K. Sharma, H. Bu, and A. Denton. 2016. Evidence for the ability of active-optical sensors to detect sulfur deficiency in corn. Agron J 108(5): 2158–2162. doi: 10.2134/agronj2016.05.0287.

Tenorio, F.A.M., E.L. McLellan, A.J. Eagle, K.G. Cassman, D. Andersen, et al. 2020. Benchmarking impact of nitrogen inputs on grain yield and environmental performance of producer fields in the western US Corn Belt. Agric Ecosyst Environ 294. doi: 10.1016/j.agee.2020.106865.

Ullah, I., D. Muhammad, and M. Mussarat. 2023. Effect of Various Nitrogen Sources at Various Sulfur Levels on Maize–Wheat Yield and N/S Uptake under Different Climatic Conditions. J Plant Growth Regul 42(3): 2073–2087. doi: 10.1007/s00344-022-10682-6.

RESEARCH PROJECT PROPOSAL BUDGET

Project Title: Enhancing Spring Wheat Yields through Split In-Season Nitrogen and Sulfur Applications in Conventional and No-Till Systems

Principal Investigator(s) / Project Director(s) Sergio Cabello Leiva	Funds Requested For Year 1 (2024)	Year 2 (2025)	Year 3 (2026)
A. Salaries and Wages	$	$	$
1. Co-principal Investigator(s)			
2. Senior Associates			
3. Research Associates – Post Doctorate			
4. Other Professionals	500	515	
5. Graduate Students			
6. Prebaccalaureate Students	1,000	1,030	
7. Secretarial - Clerical			
8. Technical, Shop and Other	6,000	6,180	
B. Fringe Benefits	4,360	4,491	
C. Consulting and Professional Services			
D. Supplies and Services	1,570	1,620	
E. Travel	4,300	4,435	
F. Sub-Contracts	1,400	1,470	
G. Repairs & Maintenance	750	775	
H. Rentals & Lease			
I. Other Expenses (Direct Cost Attachment)	11,204	11,204	
TOTAL AMOUNT OF THIS REQUEST (per year)	**$ 31,084**	**$ 31,720**	**$**

Budget Justification

Partial salary support is requested for a research specialist and research technicians to plant, maintain and harvest the trials and for part time staff to collect optical sensor data and help with trial maintenance and data collection. Fringe benefits are calculated at 60% for research specialist, 66% for technical staff, and 10% for part time staff. Repairs are for repairs to the equipment used to complete the project including tractors, planters, and combines. Operating fees are for soil sample and plant analyses. Materials and supplies are for fuel, fertilizer, chemical, plot stakes and supplies, and laboratory supplies. Travel funds are for travel to and from the trial areas during the growing season and to acquire supplies. Travel to the Minnesota site includes mileage, hotel, and per diem for trips to collect soil samples, trips for sensor data collection, and harvest. Other direct costs are lab fees for soil sample analyses and plant analyses for both locations (composite soil sample 2 sample x $35/sample = $70; soil N and S 384 samples x $17.70/sample = $6,796; Biomass N and S 128 samples x $33.9/sample = $4,338) and a contracted services agreement ($1,470) to Central Minnesota Demonstration and Research Farm in Staples for providing the test site.

Figures attachments from results 2024.

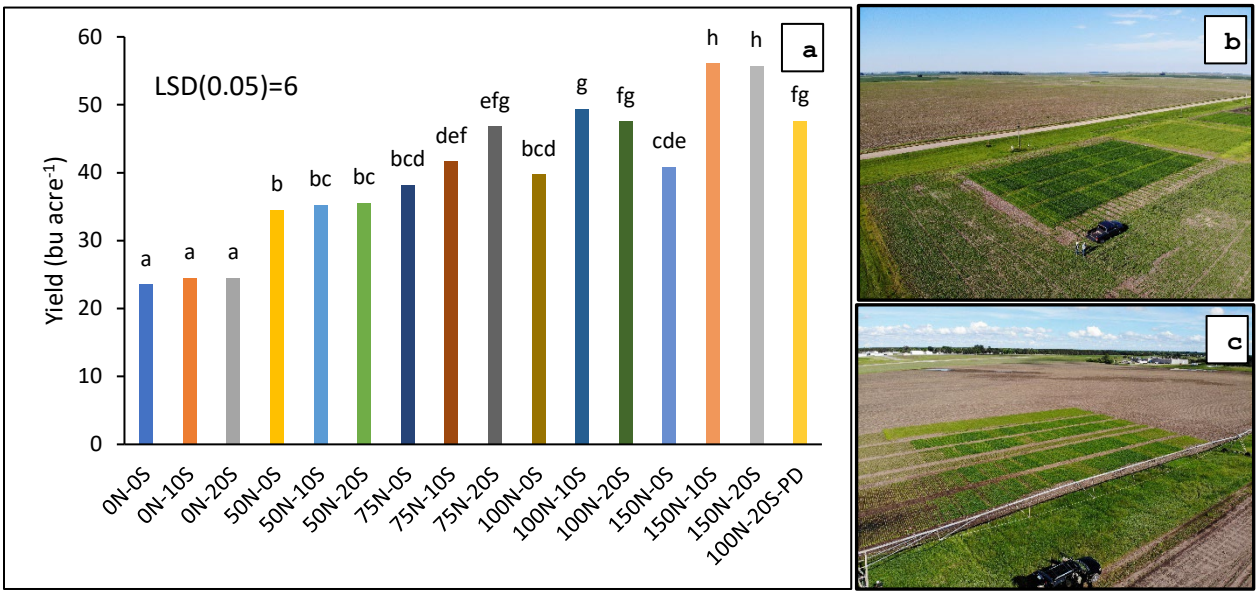

Figure 1. Wheat grain yield combined across Carrington, Mn, and Staples, MN 2023 (a). Carrington aerial picture of spring wheat field trial at Feekees 5, June 2024 (b). Staples aerial picture of spring wheat field trial at Feekees 5, June 2024 (c). Different lowercase letters above each graph bar indicate significant differences with 95% confidence.

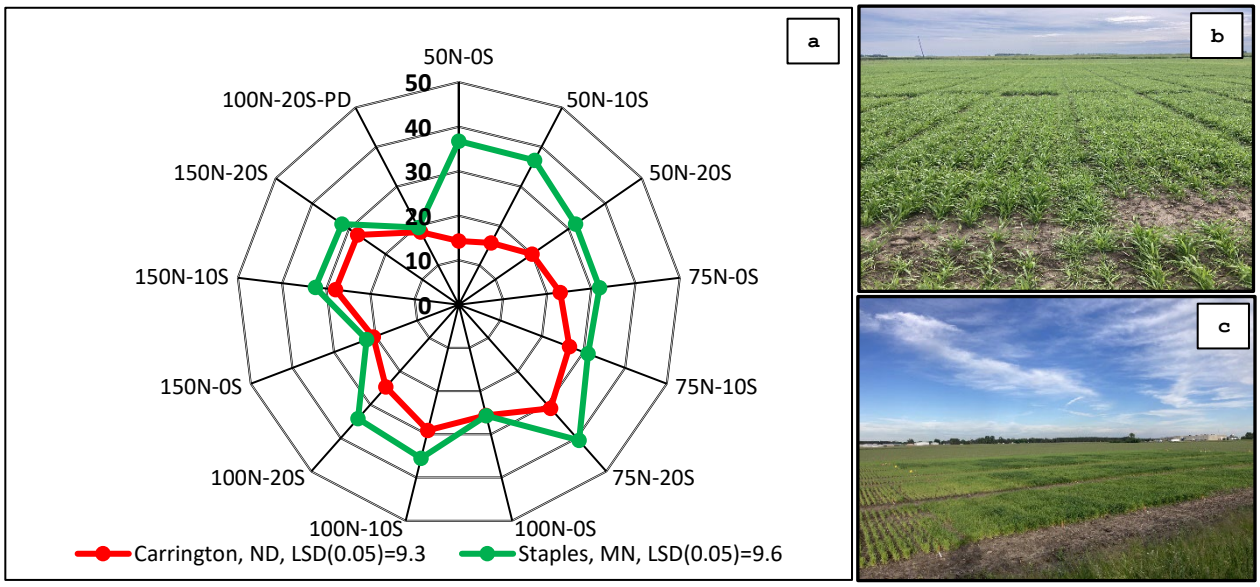

Figure 2. Wheat nitrogen use efficiency (NUE) at Carrington, ND (red line), and Staples, MN (green line) (a). Wheat field trail Carrington, ND, June 2024 9b). Wheat field trail Staples, MN, June 2024 (b).

Table1. Spring wheat initial economic analysis for a 500-acre operation averaged values from Carrington, ND, and Staples, MN, 2024

Treatment split application	Yield	Wheat gross value†	Urea‡	Ammonium sulfate§	Farming cost₣	Split application cost††	Partial Wheat net value
lb acre^{-1}	Bu	----------USD$----------					
0N-0S‡‡	11,796	83,753	4,933	0	96,337	4,610	-22,127
0N-10S‡‡	12,263	87,067	2,465	4,725	96,460	4,610	-21,194
0N-20S	12,265	87,080	0	9,450	96,461	4,610	-23,440
50N-0S	17,262	122,563	12,326	0	97,775	4,610	7,851
50N-10S	17,648	125,300	9,861	4,725	97,876	4,610	8,228
50N-20S	17,787	126,290	7,396	9,450	97,913	4,610	6,922
75N-0S	19,100	135,608	18,489	0	98,258	4,610	14,251
75N-10S	20,832	147,907	16,024	4,725	98,714	4,610	23,834
75N-20S	23,398	166,127	13,559	9,450	99,389	4,610	39,120
100N-0S	19,863	141,024	24,652	0	98,459	4,610	13,303
100N-10S	24,716	175,480	22,187	4,725	99,735	4,610	44,223
100N-20S	23,789	168,901	19,722	9,450	99,491	4,610	35,628
150N-0S	20,438	145,109	36,978	0	98,610	4,610	4,911
150N-10S	28,042	199,096	34,513	4,725	100,610	4,610	54,638
150N-20S	27,862	197,818	32,048	9,450	100,563	4,610	51,148
100N-20S-PD§§	23,807	169,027	19,722	9,450	99,496	0	40,359

† Wheat gross value was USD$7.1 per bushel

‡ Urea cost was USD$506 per metric ton

§ Ammonium sulfate cost was USD$500 per metric ton

₣ Farming cost of USD$219.31 per acre, included land rent, tillage, planting, seed, fungicide, and harvesting. Drying and hauling cost were calculated based on bushels. 2024 North Dakota custom rates

†† Split application cost considered broadcast application at USD$9.22 per acre

‡‡ These treatments considered urea application to equalized N application from ammonium sulfate treatments

§§ 100N-20S-PD treatment considered a full rate of nitrogen and sulfur fertilizer applied at planting date