Split In-Season Nitrogen and Sulfur Applications Increase Spring Wheat Yield and Quality in Conventional and No-Till Systems

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Introduction

Effective management of nitrogen (N) and sulfur (S) fertilizers is crucial for wheat production, as both nutrients are key to photosynthesis due to their role in chlorophyll production (Andrews et al., 2013). In North Dakota, many farmers over-apply N to increase yields, which is neither cost-effective nor sustainable (Tenorio et al., 2020). Although soil analysis helps guide proper N and S application, factors like temperature, rainfall, soil properties, and plant genetics can affect efficiency.

Active (GreenSeeker) and passive (drone and multispectral camera) optical sensors offer an affordable way to monitor plant N and S status in real-time. This allows for precise, mid-season recommendations that improve yield and protein content. Franzen et al. (2016) highlighted how seasonal weather changes complicate sulfur predictions in soil analysis, while active sensors can accurately detect N and S deficiencies. Their research also found that high nitrogen rates can worsen sulfur deficiency, especially in no-till systems.

Ullah et al. (2022) demonstrated that the optimal interaction between N and S significantly enhances wheat yield, emphasizing the need for updated fertilizer recommendations in Minnesota and North Dakota. Their research supports split applications of N and S for better results. Given that traditional spring soil tests may not fully reflect nutrient availability due to factors like organic matter and weather, we hypothesized that using split applications of nitrogen and sulfur would significantly increase wheat yields under conventional and no-till cropping systems.

Methodology

This research was conducted at two locations: Carrington, ND, where plots were established on dryland, no-till loamy soils, and at the Central Minnesota Demonstration and Research Irrigation Farm in Staples, MN, where plots were placed on irrigated sandy soils managed with conventional tillage. The experimental unit size was 25 ft x 10 ft.

Spring wheat (MN Rothsay) was seeded at a rate of 2.3 bu per acre in late April using a randomized complete block design (RCBD) with four replicates. Sixteen treatments were applied using urea and ammonium sulfate, with nitrogen (N) and sulfur (S) rates (lb acre^{-1}) as follows: 0N-0S, 0N-10S, 0N-20S, 50N-0S, 50N-10S, 50N-20S, 75N-0S, 75N-10S, 75N-20S, 100N-0S, 100N-10S, 100N-20S, 150N-0S, 150N-10S, and 150N-20S. Additionally, one treatment of 100N-20S was applied at planting as a control. Nitrogen and sulfur were applied in a split application, with 60% as a starter and 40% at the wheat Feekes 5 stage.

Composite soil samples were collected in early spring from 0-6 inches and 6-24 inches depths to analyze for NO3-N, soil pH, phosphorus (P), potassium (K), sulfate-S, zinc (Zn), and organic matter. The 6–24-inch samples were tested for NO3-N and sulfate-S, providing the basis for N and S recommendations. In-season soil sampling at Feekes 5 stage also tested for NO3-N and sulfate-S, and after harvest, soil samples were collected from 0-24 inches to test for NO3-N and sulfate-S.

The GreenSeeker hand-held sensor was used to collect NDVI data from each plot at Feekes stages 3, 5, and 10.5 of the wheat growth stages. Additionally, a drone equipped with a DJI Phantom 4 MicaSense Red-Edge multispectral camera captured canopy reflectance images at 550, 670, 715, and 840 nm (green, red, red-edge, and near-infrared) at the same wheat growth stages (3, 5, and 10.5).

Results

Rainfall Impact

In 2024, rainfall significantly impacted wheat production in our trial locations. From April to August, Carrington received 15.01 inches of rainfall, 32% above the average, while Staples recorded 23.3 inches, a 57% increase. This excessive rainfall increased the risk of nitrogen (N) and sulfur (S) leaching, reducing nutrient use efficiency. Treatment effects were visible, as shown in the aerial green index and NDVI images in Figure 1, especially at the wheat Feekes 5 growth stage.

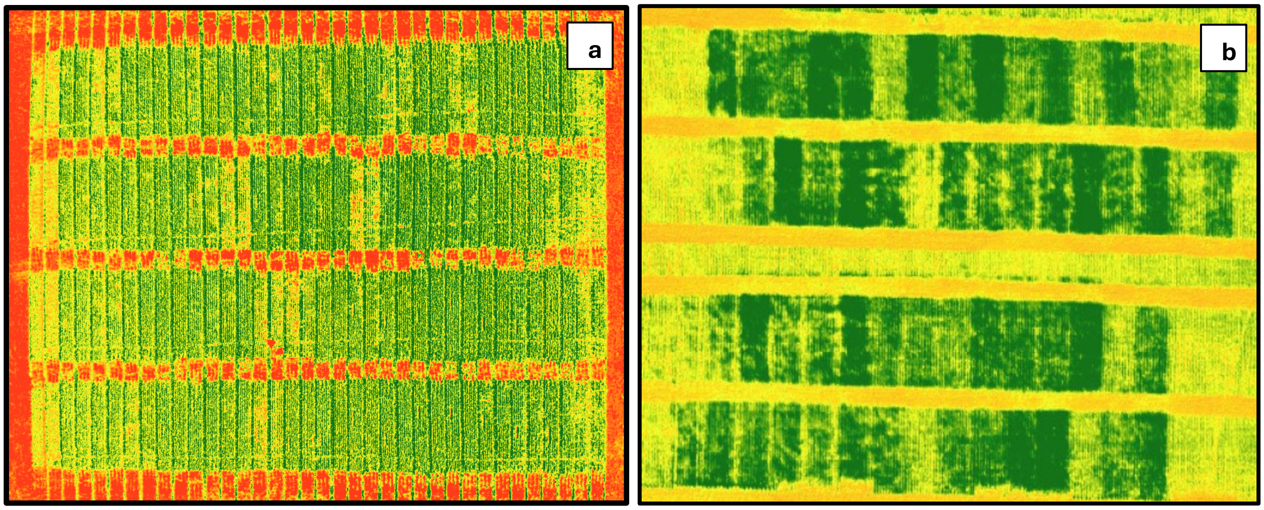

Figure 1. (a) Carrington, ND, wheat green index at Feekes 5, (b) Staples, MN, wheat NDVI index at Feekes 5.

The GreenSeeker sensor provided NDVI readings, which strongly correlated with green ground cover, as seen in Figure 2. Using this data, multiple regression models were developed to predict optimal N and S application rates at Feekes 5 for target yields. These models showed high accuracy (R^2 of 0.78 for Carrington and 0.81 for Staples), providing robust seasonal predictions for N and S applications.

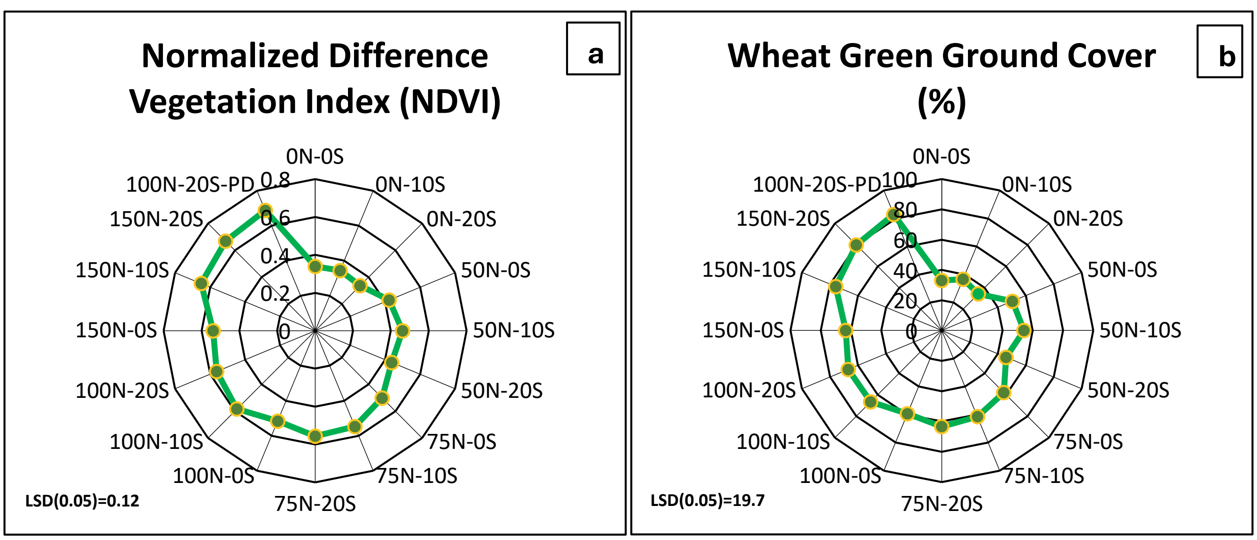

Figure 2. (a) Wheat normalized difference vegetation index (NDVI measured with GreenSeeker) at Feekes 5. (b) Wheat green ground cover (RGB smartphone photo) at Feekes 5. Both graph values were averaged across Carrington, ND, and Staples, MN, 2024.

Yield Results

Yield was a significant factor across treatments (Figure 3). Sulfur application increased wheat yield by 30.5% at the same nitrogen levels. Specifically, treatments with 150N-20S (55.7 bu/a) and 150N-10S (56.1 bu/a) outperformed the 150N-0S treatment (40 bu/a). These findings align with Franzen et al. (2016), who noted that high nitrogen rates (in this case, 150 lbs/a) can worsen sulfur deficiency, presenting challenges, particularly in no-till systems. No significant difference was observed between the treatment where 100 lbs N and 20 lbs S was applied at planting (47.6 bu/a) versus the one with a split application of 75 lbs N and 20 lbs S (46.8 bu/a). This indicates that a split application with 25% less nitrogen can be as effective as a full-rate single application at planting.

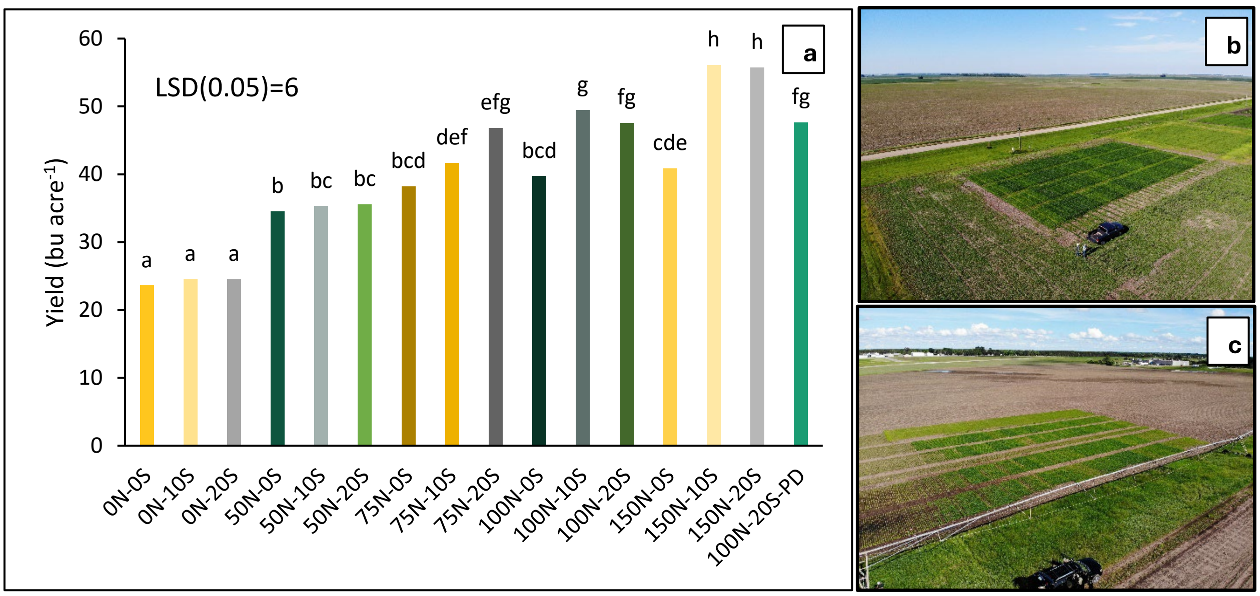

Figure 3. (a) Wheat grain yield combined across Carrington, ND, and Staples, MN ,2024. (b) Carrington aerial picture of spring wheat field trial at Feekes 5, June 2024. (c) Staples aerial picture of spring wheat field trial at Feekes 5, June 2024. Different lowercase letters above each graph bar indicate significant differences at 95% confidence.

Protein content varied between locations. In Carrington, protein levels remained above 13% across all treatments due to fertile, loamy soil under no-till conditions. In contrast, Staples exhibited protein levels below 12% in most treatments, likely due to sandy soil conditions. However, lower yields with higher N rates did show some increase in protein content. Total grain nitrogen was highest in treatments with sulfur, especially when nitrogen was reduced by 25% compared to the full rate.

Nitrogen Use Efficiency (NUE) Gains with Sulfur

Sulfur applications significantly improved nitrogen use efficiency (NUE). In Carrington, NUE increased by 7% with sulfur, and in Staples, by 10%. A split application with 75N-20S (25% less N) further boosted NUE by 13% in Carrington and 21% in Staples. This demonstrates that split applications improve yield and enhance nitrogen use efficiency (Figure 4a).

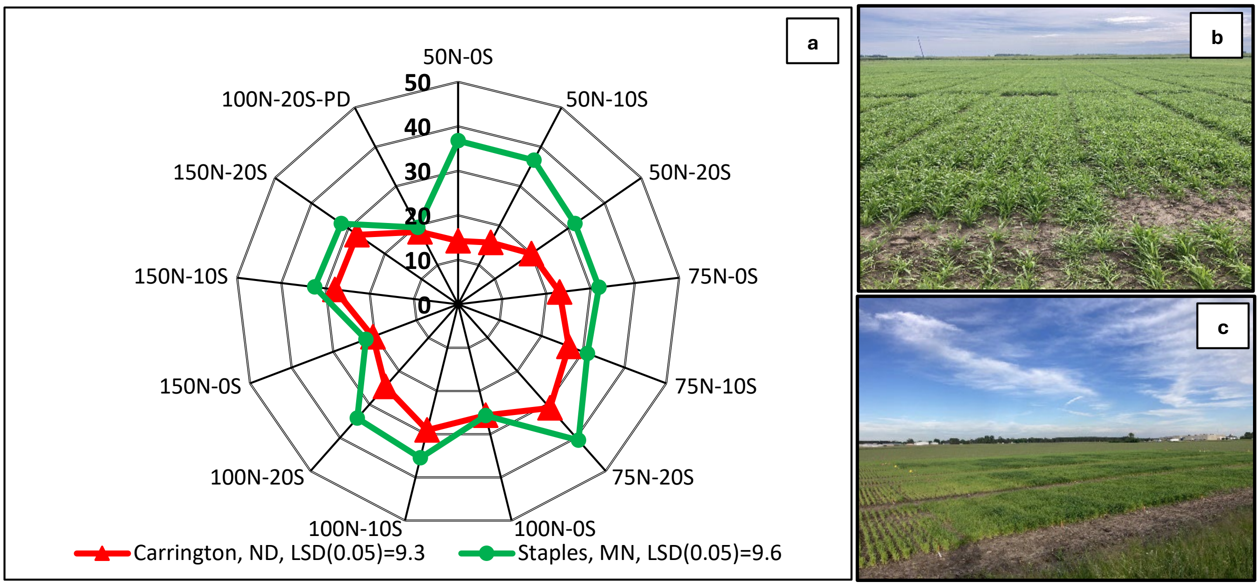

Figure 4. (a) Wheat nitrogen use efficiency (NUE) at Carrington, ND (red line), and Staples, MN (green line). (b) Wheat field trial Carrington, ND, June 2024. (c). Wheat field trial Staples, MN, June 2024.

Conclusions

Adopting sulfur and split nitrogen (N) applications offers multiple benefits for wheat production. Sulfur rates of 10 and 20 lbs per acre increased wheat yield by 30.5% at the same nitrogen levels. Additionally, split applications with 25% less nitrogen proved as effective as full-rate applications at planting. Nitrogen use efficiency (NUE) was also significantly improved with sulfur, with 7-12% improvements at the same N rate, boosting wheat yield potential in Minnesota and North Dakota.

Split N and S applications have shown the potential for higher yields with less fertilizer, providing a promising strategy for sustainable wheat production. While these results are promising, further testing will help refine N and S recommendations for varying conditions in North Dakota and Minnesota. This trial represents a positive first step toward more efficient, profitable, sustainable wheat production.

References

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