EFFICIENT NITROGEN STRATEGIES FOR HYBRID WINTER RYE

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ABSTRACT

Efficient nitrogen (N) management is essential to maximize hybrid winter rye (*Secale cereale*) yield. Given limited information on how N rates, application timing, and fertilizer sources affect production in the U.S. Midwest, yield responses were evaluated under various N management strategies. This experiment included a pre-plant application of 30 lb N ac^{-1} in the fall, followed by spring applications to evaluate eight N rates (0–210 lb N ac^{-1}) and investigate the effects of two N sources (urea and SuperU®) and two split application schedules. The split applications consisted of an initial 30 lb N ac^{-1} in March, followed by second applications of 30 or 60 lb N ac^{-1} in April or May, resulting in total N rates of 60 or 90 lb N ac^{-1}. In the first year, yield response to N rates followed a quadratic plateau, with an optimum N rate of 18 lb N ac^{-1} and maximum yield of 62 bu ac^{-1}. At 60 lb N ac^{-1}, urea and SuperU® applied in March produced similar yields (62–65 bu ac^{-1}), whereas split applications reduced yield by 5–8 bu ac^{-1}. At 90 lb N ac^{-1}, a split of 30 lb N ac^{-1} in March and 60 lb N ac^{-1} in April resulted in the highest yield (71 bu ac^{-1}), while other split timings reduced yield (59–61 bu ac^{-1}). Overall, modest spring N applications (approximately 20 lb N ac^{-1}), following an initial pre-plant fall application, were sufficient to achieve near-maximum yield, with minimal differences observed between the use of urea or SuperU®.

INTRODUCTION

Nitrogen (N) is the primary yield-limiting nutrient in cereal production, and improving N management remains essential for balancing agronomic productivity with environmental stewardship. Low recovery of applied N caused by volatilization, leaching, and denitrification continues to challenge both economic efficiency and water quality goals in the U.S. Midwest (Cassman et al., 2002; Snyder et al., 2009). As a result, strategies that increase nitrogen use efficiency (NUE) by better synchronizing N availability with crop demand have become a priority in modern cereal systems.

Conservation-based practices such as no-till and diversified crop rotations are increasingly adopted in the northern Great Plains because they enhance soil organic matter, biological activity, and N mineralization, which may reduce reliance on fertilizer inputs (Blanco-Canqui and Lal, 2008; St. Luce et al., 2017). Winter cereals may particularly benefit from these systems because their early spring growth allows them to capture mineralized N that might otherwise be lost (Campbell et al., 2011).

Despite progress in wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.), limited information exists regarding N management for hybrid winter rye (*Secale cereale*) under North American conditions. Recent advances in hybrid breeding have increased yield potential and nutrient uptake capacity, yet regional N recommendations for rye are still largely extrapolated from other small grains and may not reflect its distinct root architecture, canopy development, and seasonal N dynamics (Lollato et al., 2019). In addition, few studies have evaluated how fertilizer source and spring application timing affect hybrid rye performance within conservation systems, even as producers seek more precise N strategies to improve profitability and reduce environmental risk.

Therefore, the objectives of this study were to quantify the grain yield response of hybrid winter rye to increasing N rates and to identify the agronomic and economic optimum N rate (EONR) under southeastern South Dakota conditions. A secondary objective was to evaluate how fertilizer source and spring application timing influence yield within a no-till production system.

MATERIALS AND METHODS

Experimental Design

This study was conducted at the Southeast Research Farm (SERF) in Beresford, SD (43.0° N, 96.8° W) from October 2024 to August 2025. The soil is classified as an Egan silty clay loam, and the previous crop was soybean. Hybrid winter rye cv. 'Receptor' was planted using a no-till drill at 800,000 seeds ac^{-1}, 1 in depth, and 7.5 in row spacing. The experimental design was a randomized complete block design with four replications. Each plot measured 15 ft × 50 ft (0.009 ac), totaling approximately 0.96 ac for the trial area.

Fourteen N treatments were established to generate two complementary datasets: (i) N-rate response and (ii) timing and source effects. The rate study included eight total N rates (0, 30, 60, 90, 120, 150, 180, and 210 lb N ac^{-1}) following a uniform pre-plant application of 30 lb N ac^{-1} in the fall. The source trial evaluated two N sources: urea (46% N) and a stabilized urea containing 0.85% dicyandiamide (DCD) and 0.06% N-(n-butyl) thiophosphoric triamide (NBPT) (SuperU®, Koch Agronomic Services, Wichita, KS). The timing portion evaluated two split spring applications consisting of 30 lb N ac^{-1} in March plus an additional 30 or 60 lb N ac^{-1} in April or May for total N rates of 60 and 90 lb N ac^{-1}.

Daily precipitation and temperature data (March–July 2025) were obtained from the NOAA National Centers for Environmental Information (NCEI, 2025). Data were accessed through the Climate Data Online portal (https://www.ncdc.noaa.gov/cdo-web/), representing the post-dormancy and peak water-demand phases critical for rye yield formation.

Soil Sampling and Analysis

Before spring N applications, 20 soil cores per replication were collected in a zigzag pattern at 0–6 in and 6–24 in depths. Samples were stored in coolers, transported to South Dakota State University (Brookings, SD), refrigerated until processing, air-dried, ground, and sieved (2 mm). Chemical analyses were performed by Ward Laboratories Inc. (Kearney, NE), a certified commercial laboratory using standard soil fertility procedures.

Crop Management and Harvest

Weed control was achieved with bromoxynil (Buctril®, 2,6-dibromo-4-cyanophenyl octanoate; Bayer CropScience, Research Triangle Park, NC) applied on May 23, 2025, at 2 pt ac^{-1}. Plots were harvested on August 13, 2025, using a Wintersteiger Quantum Pro combine harvester (WINTERSTEIGER AG, Ried im Innkreis, Austria). Grain weight was recorded and adjusted to 14% moisture for yield determination.

Statistical Analysis

Data were analyzed using a randomized complete block design with four replications. Residual plots indicated no violations of normality or homogeneity of variance assumptions. Treatment means for the timing and source experiment were compared by ANOVA followed by Tukey's HSD test at $P \leq 0.05$. Outliers identified through diagnostic plots were removed prior to analysis to ensure model accuracy and homogeneity of residuals.

The economic optimum nitrogen rate (EONR) was determined using a quadratic-plateau regression model (Cerrato and Blackmer, 1990; Scharf et al., 2005) fitted to grain yield data from the N-rate trial. A nitrogen price of US$ 0.65 lb^{-1} N and a rye grain price of US$ 5.80 bu^{-1} were used to calculate the economic optimum, reflecting current national market values (USDA-ERS, 2025; USDA-NASS, 2025). The resulting price ratio (N price:grain price) was 0.11. Modeling was conducted using JMP® Student Edition (Version 18.2.2; SAS Institute Inc., Cary, NC) with nonlinear least-squares procedures to estimate EONR and the corresponding yield values.

RESULTS AND DISCUSSION

Grain Yield Response to N Rate

Grain yield of hybrid winter rye responded to N rate following a quadratic-plateau relationship (Fig. 1). Yield increased with N additions up to an agronomic optimum of 18 lb N ac^{-1}, achieving a maximum yield of 62 bu ac^{-1}. Beyond this rate, yield plateaued, indicating no additional response to further N inputs. Yields were lower than expected likely due to early season drought conditions. The economic optimum N rate (EONR) was 10 lb N ac^{-1}, resulting in a yield of 61 bu ac^{-1}. The relatively low N requirement suggests that residual soil N and mineralization from the previous soybean (*Glycine max* [L.] Merr.) crop were sufficient to support early growth under no-till management.

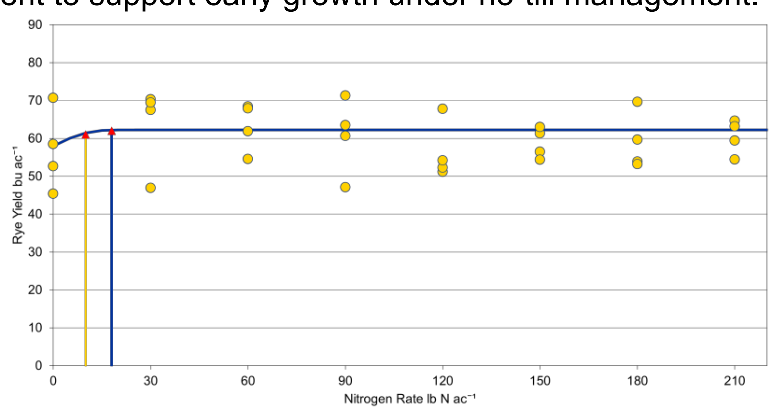

Fig. 1. Relationship between hybrid winter rye grain yield and applied N rate modeled with a quadratic-plateau function. The agronomic optimum N rate (AONR) was 18 lb N ac^{-1} (62 bu ac^{-1}), while the economic optimum N rate (EONR) was 10 lb N ac^{-1} (61 bu ac^{-1}).

Similar quadratic-plateau responses to N rate have been reported for winter wheat and barley in the northern Great Plains, with optimum N rates commonly ranging between 60 and 100 lb N ac^{-1} (Halvorson et al., 2002; Campbell et al., 2011). The much lower optimal N rate observed here may reflect a combination of high residual mineral N after soybean, the enhanced N retention typically associated with conservation systems, and reduced yield due to early season drought conditions (Blanco-Canqui and Lal, 2008). Such results align with previous observations that diversified rotations and minimal tillage improve synchronization between soil N supply and plant uptake, thereby lowering fertilizer demand without compromising yield potential (Varvel, 2000; St. Luce et al., 2017).

N Source and Timing Effects

At the 60 lb N ac^{-1} rate, rye yield averaged 65 bu ac^{-1} for SuperU® and 62 bu ac^{-1} for urea when applied in March, with no statistical difference ($P > 0.05$) between sources. Compared to single applications, split applications of SuperU® (March + April or March + May) produced lower yields (59 and 55 bu ac^{-1}, respectively), representing a 5–10 bu ac^{-1} reduction. At the 90 lb N ac^{-1} rate, the timing of N application had a greater influence. The March + April SuperU® split produced the highest yield (71 bu ac^{-1}, group A), while March single applications of either source yielded moderately (68 and 59 bu ac^{-1} for SuperU® and urea, respectively). However, delaying the second split to May reduced yield to 62 bu ac^{-1}. These results indicate that early-season N availability is critical for maximizing rye yield and that splitting up the N application did not improve yield substantially (Fig. 2).

Comparable findings have been reported in winter wheat and barley systems, where early N application enhances tiller survival and head density, leading to greater yield stability (Grant and Flaten, 2019; Lollato et al., 2019). Conversely, delayed topdressing beyond the stem-elongation phase has been shown to limit N uptake and reduce kernel set under dry spring conditions (St. Luce et al., 2017). The superior performance of the March + April split at 90 lb N ac^{-1} in this study supports the concept that maintaining available N through early reproductive growth stages enhances grain formation, while later splits (March + May) provide minimal physiological benefit.

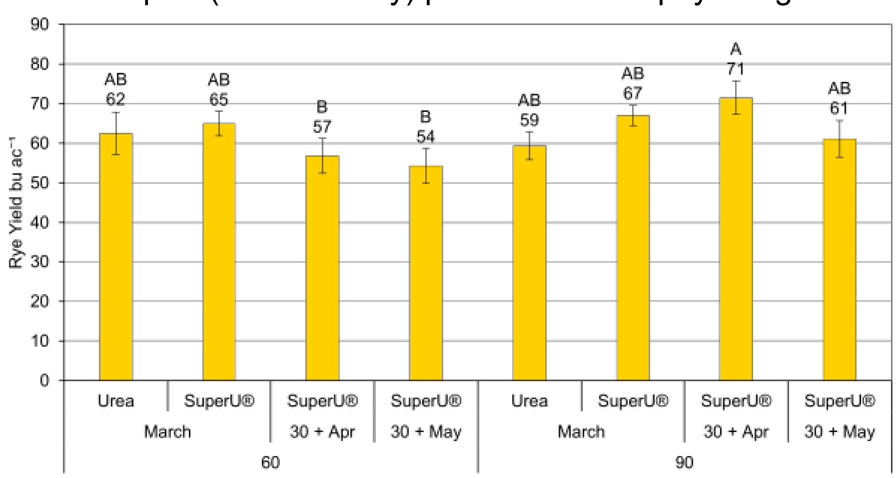

Fig. 2. Mean grain yield of hybrid winter rye as affected by N source (urea, SuperU®) and spring application timing (single and split). Bars represent treatment means ± standard error. Different letters indicate significant differences at $P \leq 0.05$ (Tukey's HSD).

Economic Interpretation

Economic analysis showed diminishing returns to N inputs beyond the agronomic optimum. The calculated price ratio of 0.11 (US$ 0.65 lb^{-1} N: US$ 5.80 bu^{-1} grain) identified an EONR of 10 lb N ac^{-1}, corresponding to near-maximum yield (98% of yield at the agronomic optimal N rate). The net return to N decreased beyond this rate, emphasizing the limited economic benefit of excessive fertilization under moderate N requirements.

The nitrogen price of US$ 0.65 lb^{-1} N reflects current national fertilizer costs (USDA-ERS, 2025), while the rye grain price of US$ 5.80 bu^{-1} represents the 2024 U.S. marketing-year average reported by USDA-NASS (2025). While hybrid cultivars were used in this study, national market data do not differentiate prices between hybrid and open-pollinated rye.

Similar economic relationships between N investment and yield gain have been observed for cereal systems across the U.S. Midwest, where EONR values generally occur at 90–95% of the agronomic optimum N rate (Scharf et al., 2005; Kitchen et al., 2017). These findings highlight the importance of balancing input costs with marginal yield response, particularly when price ratios are below 0.15. Under such conditions, conservative N rates applied early in the season provide optimal profitability while minimizing risk of N loss and environmental impact (Raun and Johnson, 1999).

Climatic Context and Implications

During the 2025 growing season (March–July), mean monthly air temperature ranged from 41 °F in March to 75 °F in July, averaging slightly above the 30-year mean (Fig. 3). Precipitation was below average in April (1.7 in) and May (2.0 in), indicating mild early-season water stress during tillering and stem elongation. In contrast, July precipitation (8.0 in) exceeded the long-term mean (2.7 in) and likely favored grain filling.

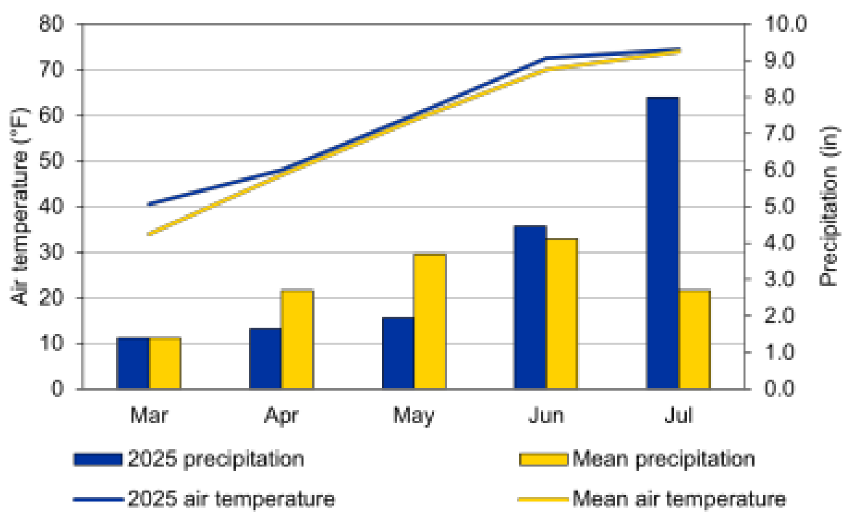

Fig. 3. Monthly air temperature and precipitation during the 2025 growing season compared with the 30-year mean (1994–2024) at Beresford, SD.

Weather variability is a known driver of N response in northern small-grain systems (Campbell et al., 2011). The pattern observed here, a dry spring followed by wetter mid-summer, may have temporarily limited early N uptake but later supported strong grain filling. At the state level, South Dakota rye yield in 2025 (55 bu ac^{-1}) was comparable to 2024 (56 bu ac^{-1}) (USDA-NASS, 2025), suggesting that while local weather likely influenced physiological development at this site, it did not represent a statewide yield penalty. Overall, the conditions provided a realistic framework to evaluate N management strategies for hybrid rye under variable spring moisture typical of the region.

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