HARVESTING TIME BASED ON GROWING DEGREE DAYS INFLUENCED WINTER CEREAL RYE MORPHOLOGICAL TRAITS, FORAGE YEILDS, QUALITY, AND FARM PROFIT IN POORLY DRAINED ALFISOLS

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ABSTRACT

Winter cereal rye (*Secale cereale* L.) (WCR) is often double-cropped with maize for silage (*Zea mays* L.) to increase forage supply and farm profit. Spring nitrogen (N) fertilization of WCR can influence production and quality at various harvesting times. The experiment was conducted over the 2019–2021 growing seasons to evaluate the effects of harvesting time (late March to end of April based on growth stage) and spring N fertilization (0 and 47 kg N ha^{-1}) on WCR morphology, forage yield, nutrient removal, quality, and farm profit. A quadratic model best described the increase in WCR dry matter (DM) yield with growing degree day (GDD) accumulation ($R^2 = 0.81$). As GDD increased, WCR relative forage quality (RFQ) declined linearly. Benchmarking RFQ at 150 for dairy milk production indicated WCR should be harvested at a GDD of 543, at which plant height was 31.8 cm and DM yield was 0.77 Mg ha^{-1}. Harvesting at a GDD of 668, where RFQ was suitable for heifer production, produced a plant height of 71 cm and DM yield of 2.25 Mg ha^{-1}. If harvesting WCR occurs early at GDDs lower than 744, no N fertilizer in spring is required. If the goal is to maximize DM yield and forage quality is less critical, then N fertilization is needed to increase DM yield at later harvesting times (GDDs > 744). Therefore, N need of WCR depends on the harvesting time or growth stage.

INTRODUCTION

Dairy farmers must balance profitability, animal nutrition, and environmental sustainability. In corn silage–alfalfa rotations, Illinois growers often “double crop” winter cereal rye (WCR) with corn silage, benefiting soil health, nutrient cycling, and forage supply (Nair & Ngouajio, 2012; Lyons et al., 2019). Profitability in this system depends on managing WCR nitrogen (N) and harvest timing (Mirsky et al., 2017), with high-quality forage generally harvested from boot to early heading stages (Zadoks et al., 1974). Later stages increase yield but often reduce forage quality (Collar & Askland, 2001). Studies show that as WCR matures, acid detergent fiber (ADF), neutral detergent fiber (NDF), and lignin increase, while crude protein (CP), total digestible nutrients (TDN), and relative forage quality (RFQ) decrease.

Understanding WCR's N requirements is essential to maximizing profit and minimizing environmental impacts. N is a significant cost, and optimal rates vary based on factors like manure history, soil organic matter (SOM), and harvest timing; fields with high SOM may require minimal N (Lyons et al., 2019). On farms with manure history, it is critical to assess if high-SOM soils respond to spring N fertilization to improve sustainability and profitability, given forage quality influences price (Halopka, 2023). Nitrogen application can improve WCR dry matter (DM) yield, CP, dry matter digestibility (DMD), TDN, and RFQ (Delevatti et al., 2019). However, excessive N may reduce fiber digestibility and unbalance livestock diets, impacting economic returns.

This study aimed to assess the effect of harvest timing, based on growth stage, and N addition on WCR's (i) morphophysiological traits; (ii) forage yield and quality parameters (e.g., CP, TDN, RFQ); (iii) N requirements; and (iv) farm profit. We hypothesized that in soils with high SOM (>30 g kg^{-1}) and fall-applied manure, no spring N might be required for WCR optimum production.

MATERIALS AND METHODS

Field experiments took place near Breese, IL, from October 2019 to April 2021. Initial soil samples were taken to 20 cm for physical and chemical analysis. The trial followed a randomized complete block design with five replicates, conducted over two years (2019–2020 and 2020–2021), with 3.3 m x 5 m plots. Treatments consisted of five WCR harvest times from late March to late April, based on Feekes and Zadoks scales (Large, 1954; Zadoks et al., 1974), and two N rates (0 and 47 kg N ha^{-1}). WCR plots were fertilized with liquid dairy manure at 34 kL ha^{-1}, seeded at 90 kg ha^{-1} following corn silage in October, and top-dressed with urea in March (Vaughn et al., 2024). Plant height, leaf area index (LAI), and biomass were measured weekly from late March to late April. Biomass samples were collected from a 0.675 m^2 area within each plot, dried at 48°C for 72 hours for dry matter (DM) yield, and then ground for forage quality analysis (Weidhuner et al., 2019).

Forage quality indices, determined using near-infrared reflectance spectroscopy (NIRS), included CP, ADF, NDF, NDFD, NFC, fat, ash, and lignin. Calculations were made for total digestible nutrients, dry matter digestibility (DMD), in vitro dry matter digestibility (IVDMD), dry matter intake (DMI), relative forage quality (RFQ), net energy gain (NEG), lactation (NEL), maintenance (NEM), N removal, partial factor productivity (PFP), apparent N fertilizer recovery (ANFR), and nitrogen use efficiency (NUE) (Vaughn et al., 2024).

The economic analysis evaluated forage yield and quality responses to harvest timing (GDD) and N rates, incorporating costs for urea, operations, forage prices, and RFQ levels. Sensitivity analysis considered average forage prices and adjustments at 80% and 120%, accounting for N operational, urea, and fixed costs as inputs. Yield and quality impact forage price (Vaughn et al., 2024).

Data were analyzed using PROC MIXED. In this split-plot design, N rate was assigned to main plots and harvest timing to subplots. For significant interactions, regression against growing degree days (GDD) by year employed linear, quadratic, and exponential models (JMP Pro 14). Model selection was based on p-values, R^2, and root mean square error (RMSE). Fisher's LSD test and contrast analysis were applied for mean separation (P ≤ 0.05).

RESULTS AND DISCUSSION

Winter cereal rye plant height was significantly affected by year, N rate, harvesting time, and year x harvesting time interaction (P ≤ 0.05). Averaged across GDDs, plants were taller in 2021 (84.9 cm) than in 2020 (59.5 cm), due to higher GDDs in 2021. Plants were taller in 2021 at each sampling date (Fig. 1A). Leaf area index (LAI) was influenced by N rate, harvesting time, and their interaction. At the fertilized rate of 47 kg N ha^{-1} (N47), LAI reached its maximum at 744 GDD, suggesting that fertilized WCR maintained maximum LAI up to the heading stage (Fig. 1B). For the unfertilized control (N0), LAI was maximized at 620 GDD. WCR dry matter (DM) yield was impacted by year, harvesting time, and interactions between year × harvesting time and N rate × harvesting time. DM yield was lower in 2020 (1.79 Mg ha^{-1}) compared to 2021 (2.93 Mg ha^{-1}). Harvesting time affected DM accumulation differently each year (Fig. 1C&D).

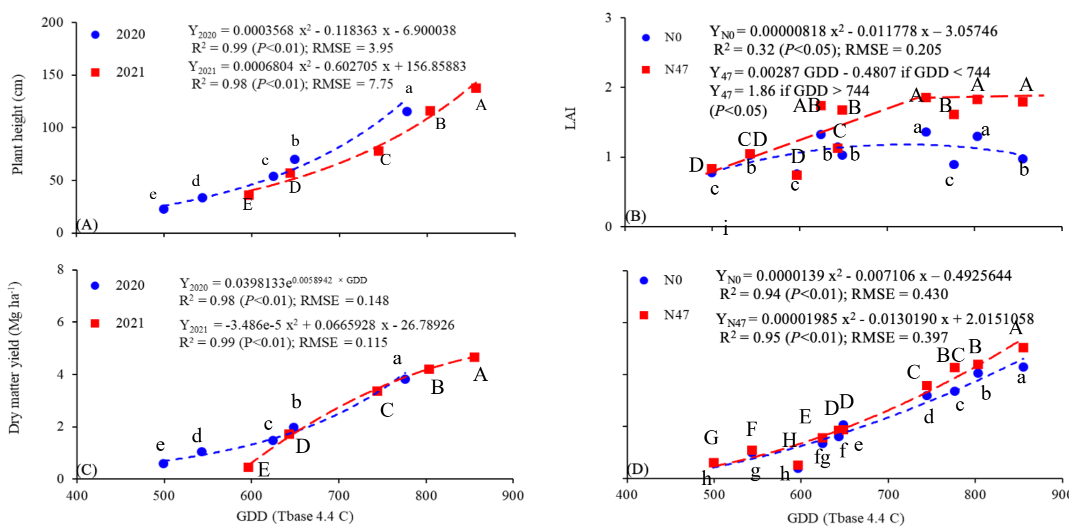

Fig. 1. The year × growing degree day (GDD) interaction for winter cereal rye plant height (A) and dry matter (DM) yield (C), and N rate × GDD interaction for leaf area index (LAI) (B), and DM yield (D) at Breese, IL USA

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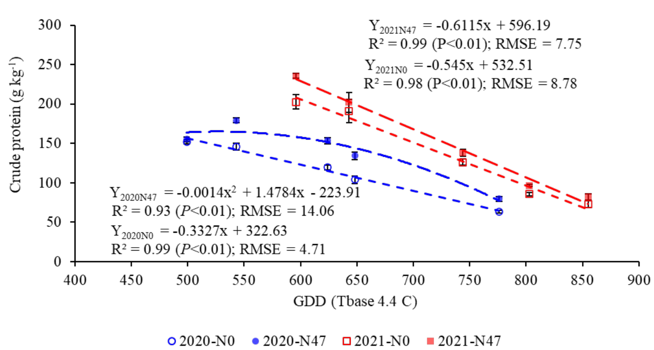

Fig. 2. The year × N rate × GDD interaction for WCR CP concentration at Breese, IL USA. Values are the means of five replicates. RMSE= Root means square error. The bars indicated as standard error. N0 = zero-N; N47 = 47 kg N ha^{-1}.

For forage quality indicators, CP was influenced by year, N rate, harvesting time, year × harvesting time, and year × N rate × harvesting time interaction. At the initial harvesting time, CP was higher in N47 than N0 in 2021 but similar in 2020, both higher in 2021 (Fig. 2). Acid detergent fiber (ADF), NDF, lignin, fat, NEL, NEM, NEG, and TDN were all influenced by year, harvesting time, and year × harvesting time interaction ($P \leq 0.05$). An increase in ADF, NDF, and lignin with an increase in GDD accumulation means WCR fat, NEL, NEM, NEG, and TDN decreased by delaying the harvesting time. Dry matter digestibility (DMD), DMI, IVDMD, and NDFD were all influenced by year, harvesting time, and year × harvesting time interaction ($P \leq 0.05$). Dry matter intake potential was higher in the first four harvesting times in 2021 than in 2020, indicating higher quality forage as reflected by the lower NDF and higher TDN in 2021 than in 2020 in these sampling dates. The DMI potential (16.6 g kg^{-1} averaged over the two years) was similar between the two years only in the final harvesting time when WCR was headed. Neutral detergent fiber digestibility (NDFD) was also higher on all harvesting times in 2021 than in 2020. Relative forage quality was only affected by harvesting time and year × harvesting time interaction ($P \leq 0.05$). Relative forage quality was similar in the initial sampling dates between the two years. The RFQ was 6 and 15% higher in sampling dates 2 and 3, respectively, in 2021 (Fig. 3).

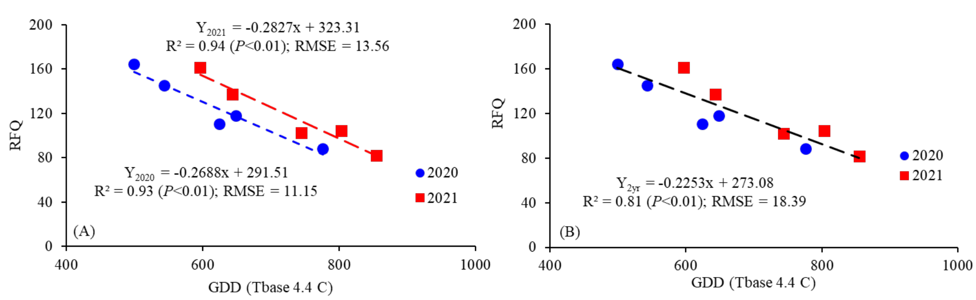

Fig 3. The year × growing degree day (GDD) interaction and linear model relation for WCR RFQ (A) and averaged over the two years (B) at Breese, IL USA. Values are two N rates and five replicates. RMSE = root mean square error.

Our results indicated that regardless of GDD, at every sampling date, profit decreased by N fertilization. In 2021, the highest profit occurred at GDD of 744-803 for both N0 vs. fertilized treatments. Similar to 2020, adding N fertilizer decreased profit at every sampling date, in line with our hypothesis that spring N addition at early harvest for high RFQ is not economical in soils with high SOM with previous manure history. Additionally, there was a harvest reduction at all harvesting dates, therefore, growers must evaluate their field history of manure management and soil capacity to deliver N in spring when fall manure is applied.

If harvesting WCR occurs early at GDDs lower than 744, no N fertilizer in spring is required. If the goal is to maximize DM yield and forage quality is less critical, then N fertilization is needed to increase DM yield at later harvesting times (GDDs > 744). To produce high-quality forage for milking cows (RFQ > 150), WCR should be harvested at 31.8 cm height when DM yield is at 0.77 Mg ha^{-1}. If the goal is to produce a lower quality for heifer/beef production, an RFQ of 125-30 is desirable. To achieve an RFQ of 125, WCR should be harvested at 71 cm height, at which the forage DM yield is 2.25 Mg ha^{-1}. Higher forage value prices had a higher effect on increasing profit than lower fertilizer and operation costs. Thus, under high forage quality and increased forage value, fertilizing may benefit growers, but as the value of forage decreases or fertilizer price increases, it does not pay off, even with increased yields. Such results have sustainability implications because adding N in spring means increased farmer costs, and not capturing the N benefit means higher unused N in the soil system, which could lead to more significant N losses.

CONCLUSIONS

A critical decision for growers in the Midwest USA managing WCR double-cropped with corn silage is finding best management practices. Our results indicated that harvest should occur at a growing degree day (GDD) of 543 to achieve a desirable relative forage quality (RFQ) of 150 with 0.77 Mg DM ha^{-1}. However, economic analysis showed that an RFQ of 125 at a GDD of 668 with a 2.25 Mg DM ha^{-1} yield was more profitable than the higher-quality forage. In determining whether WCR requires N fertilizer, we concluded that high-quality, low-yielding WCR does not require fertilization, while lower-quality, high-yielding WCR could benefit from 47 kg N ha^{-1}. Future research should evaluate harvesting time and N fertilization rates (in fall vs. spring) to determine the optimum N requirement of WCR for maximizing profit while minimizing the environmental footprint.

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