Kansas Agricultural Experiment Station Research Reports

Volume 7
Issue 8 *Kansas Fertilizer Research*

Article 7

2021

Timing, Source, and Placement of Nitrogen Fertilizer Increases Wheat Yield and Protein Content in High Yielding Environments

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Summary

The efficiency of nitrogen (N) fertilizer management depends on rate, timing, placement, and source, but the benefits of an integrated program have not been clearly quantified, to our knowledge. This study aimed to investigate the effects of integrated N management on winter wheat grain yield, grain protein content, grain test weight, and biomass in Kansas. The study consisted of two N management treatments: Normal (single N application as UAN using broadcast nozzles with the absence of urea inhibitors); and Progressive (split N application into two timings using streamer bars with urease inhibitors). Both treatments had similar results in all variables measured at Hutchinson, which was the lowest yielding location. In Ashland Bottoms, the number of heads/ft^2 and total aboveground biomass did not differ significantly between the treatments. However, grain yield, grain test weight, and protein content were significantly greater in the progressive N management. These results demonstrate the enhanced N use efficiency (NUE) of progressive N management in higher-yielding environments by better N allocation in the plant. This research demonstrates that it is possible to increase both grain protein content and grain yield in high rainfall areas without extra amounts of N fertilizer.

Introduction

Nitrogen is an essential element for crops, and genetic advances have enhanced a plants' ability to take up higher amounts of N (de Oliveira Silva, 2020a), which resulted in crop intensification with greater N fertilizer inputs in the system (de Oliveira Silva, 2020b). However, nearly 50–70% of the N applied in the soil is lost (Hodge et al., 2000). Poor N management partially causes large yield gaps in winter wheat in Kansas (Patrignani et al., 2014). Closing yield gaps is essential for food security and requires crop intensification to more efficiently use resources (e.g. water, fertilizer, energy, and land) due to the finite source from nature (Fischer et al., 2012). To maximize yields, a higher amount of the N already applied must be available for plants. In general, NUE is defined by the increment of crop yield per unit of N fertilizer added. Enhancing N uptake efficiency by the plant is the key to high NUE in cropping systems.

A few strategies are used to optimize N uptake by the plant without adding extra fertilizer, such as the method of fertilizer placement (e.g. broadcasting, injection, or streamer bars), splitting of N application, and including N inhibitors with N fertilizer (Fisher et al., 1993). Studies have shown that wheat grain yield and protein as affected by N application timing depends on the yield environment (Lollato et al., 2019b, Lollato et al., 2020), which is highly site-specific. This way, finding the optimal N application timing to enhance yields and grain protein content is a continuous process. Also, few studies have shown the effects of an integrated N management plan in response to the increase in NUE in crops. Thus, this study aimed to investigate whether an intensified N management strategy (i.e., improved timing, source, and placement) would affect grain yield, grain protein content, grain test weight, and biomass of winter wheat in Kansas.

Material and Methods

Field Set-Up

The study was carried out during the 2019–2020 winter wheat growing season at the Agronomy Farm in Ashland Bottoms, KS (fine-silty, mixed, mesic Cumulic Haplustoll) and at the South-Central Experiment Field in Hutchinson (fine-loamy, mixed, thermic Typic Argiustolls), both under rainfed conditions. Zenda winter wheat variety was planted at 90 lb/a in no-tilled soybean stubble in both locations. Wheat was drilled at 7.5-in. spaced rows using a 9-row Great Plains 506 no-till drill. Plots were 40-ft wide and 50-ft long, thus a total plot area of 2,000 ft^2. In 2019, sowing dates in Ashland Bottoms and Hutchinson were October 24 and 28, respectively. Diammonium phosphate (DAP 18-46-0) starter fertilizer was used in the plots at 50 lb/a in both locations.

Weeds, diseases, and pests were kept under control so they were not limiting factors in this research. In Ashland Bottoms and Hutchinson, harvest occurred on July 7 and June 17, respectively, using a Massey Ferguson XP8 small-plot, self-propelled combine. The central portion of the plot was harvested for grain, approximately 300 ft^2 of area.

Experimental Design and Statistical Analysis

The field experiment was set up as a randomized complete block design, with four replications. Treatments consisted of two N management treatments: Normal and Progressive (Table 1). Treatments differed in application timing, placement, and presence or absence of N inhibitors. In both N management treatments, 80 lb/a of N was applied. Normal N management consisted of one single application of N in March (Feekes 4), as broadcasting UAN with flat fan nozzles and no urease inhibitor. Progressive N management consisted of N applied in two timings (40 lb/a in each): March (Feekes 4) and early April (Feekes 7), using streamer bar applicator and urease inhibitors. Statistical analysis was performed using the PROC GLIMMIX procedure in SAS v. 9.4 (SAS Inst. Inc., Cary, NC). Replication was treated as a random effect, and locations were analyzed separately due to high variation in yield environments between the two areas.

Measurements

The soil was sampled in each plot (0 to 6 in. depth) for initial fertility, and results from soil analysis were averaged across blocks (Table 2). Whole plant biomass samples were taken in a representative 2.2-ft^2 area of the plot at wheat maturity, from which aboveground biomass and number of heads per area were measured. Lastly, grain yield, grain test weight, and grain protein content were also evaluated.

Results

Weather Conditions

Precipitation was historically above average in Ashland Bottoms (34.3 in., Figure 1) and on average in Hutchinson (14 in., Figure 2) during the winter wheat growing season. Temperatures during the experiment year did not vary considerably from the 30-year average temperature except in October, which had colder temperatures in both locations (Figures 1 and 2). In Ashland Bottoms, above-average precipitation during spring and summer resulted in a longer growing season, delay in harvesting until mid-July, and above-average yields (average yield: 64.5 bu/a).

Grain Yield

In Ashland Bottoms, where precipitation exceeded the normal average, progressive N management had a significantly greater yield than the normal N management (66 versus 63 bu/a, respectively, Table 2). This is likely due to reduced N losses in the soil by splitting the amount of N applied and use of N inhibitors, especially in the wetter environment that could result in higher N losses. Also, streamer bar applicators are more likely to minimize volatilization and N immobilization and avoid leaf burn. Broadcast application can lead to interception of spray droplets in the previous crop residue, and also can cause leaf burn for being applied directly in the crop canopy (Bly and Woodard, 2003).

The lowest yielding location was Hutchinson (average yield: 39 bu/a), likely due to the lower precipitation. In this location, yields were not significantly different between both N management treatments (Table 3). Also, low rainfall environments are less prone to N losses in the soil, so splitting N application and including N inhibitors did not significantly improve NUE.

Overall Nitrogen Management on Other Variables

The number of heads/ft^2 and total aboveground biomass did not differ significantly between the treatments in both locations (Tables 2 and 3). Grain test weight and protein content were significantly higher in the progressive N management treatment (Table 2) at Ashland Bottoms. Similar amounts of biomass and number of heads produced, along with higher grain test weight and protein content, shows the enhanced NUE of progressive N management in higher-yielding environments. In Hutchinson, no differences were seen between treatments on grain test weight and protein content, implying that water can be a limiting factor on N allocation in the plant, and hence NUE.

Preliminary Conclusions

Integrated N management (i.e. the progressive treatment) provided evidence that NUE can be enhanced without adding extra fertilizer in a high-yielding environment. The results from this research showed that the plants could better allocate N in the grain and increase protein content without trading-off biomass production, number of heads, and consequently grain yield. This research also shows that it is possible to increase both grain yield and grain protein content in environments with historically higher precipitation, which usually decreases grain protein content—lastly, winter wheat's response to nitrogen management is highly dependent on environment.

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Table 1. Description of nitrogen management treatments (i.e. application timing, N inhibitor additive, and placement method) in winter wheat at Feekes 4 and Feekes 7 stages of plant development at Ashland Bottoms and Hutchinson, KS, in 2020

N manage-ment	Feekes 4		Feekes 7		
	Nitrogen[a]	Additive[b]	Nitrogen	Additive	Placement
Normal	80 lb/a	---	---	---	Broadcast
Progressive	40 lb/a	Nitrogen inhibitors	40 lb/a	Nitrogen inhibitors	Streamer bar

[a]Source: Urea ammonium nitrate (UAN 28-0-0).
[b]Nitrification inhibitor (Centuro, Koch Agronomic Services Co., Wichita, KS 67220) at 5 gallons per ton of fertilizer (UAN); and urease + nitrification inhibitor (Agrotain Plus SC, Koch Agronomic Services Co., Wichita, KS 67220) at 3 gallons per ton of fertilizer (UAN).

Table 2. Initial soil fertility analysis at Ashland Bottoms and Hutchinson, KS, during the 2019–2020 winter wheat growing season

Location	pH	P-M	K
		----------------------- ppm	-----------------------
Ashland Bottoms	6.6	14.3	317
Hutchinson	5.5	60.2	413

Soil fertility levels were based on the first 0- to 6-in. depth and included soil pH, Mehlich-3 extractable phosphorus (P), and potassium (K).

Table 3. Effect of nitrogen (N) management[a] on winter wheat grain yield, grain protein content, test weight, aboveground biomass, and number of heads/ft^2 at Ashland Bottoms, KS, during the 2019–2020 growing season

N management	Heads/ft^2	Biomass	Test weight	Protein	Yield
		lb/a	lb/bu	%	bu/a
Normal	87 a†	11624 a	57 b	11.7 b	63 b
Progressive	82 a	11426 a	58 a	12.4 a	66 a

† Means within each column followed by the same letter are not significantly different at $\alpha = 0.05$ level using least-squares means.
[a] N management: Normal (single N application using broadcasting applicator with the absence of N inhibitors); and Progressive (split N application into two timings using streamer bars with the presence of N inhibitors).

Table 4. Effect of nitrogen (N) management[a] on winter wheat grain yield, grain protein content, test weight, aboveground biomass, and number of heads/ft^2 at Hutchinson, KS, during the 2019–2020 growing season

N management	Heads/ft^2	Biomass	Test weight	Protein	Yield
		lb/a	lb/bu	%	bu/a
Normal	50 †	6852	59	11.2	38
Progressive	48	6824	59	11.6	40

† There were no statistical differences at $\alpha = 0.05$ level using least-squares means.
[a] N management: Normal (single N application using broadcasting applicator with the absence of N inhibitors); and Progressive (split N application into two timings using streamer bars with the presence of N inhibitors).

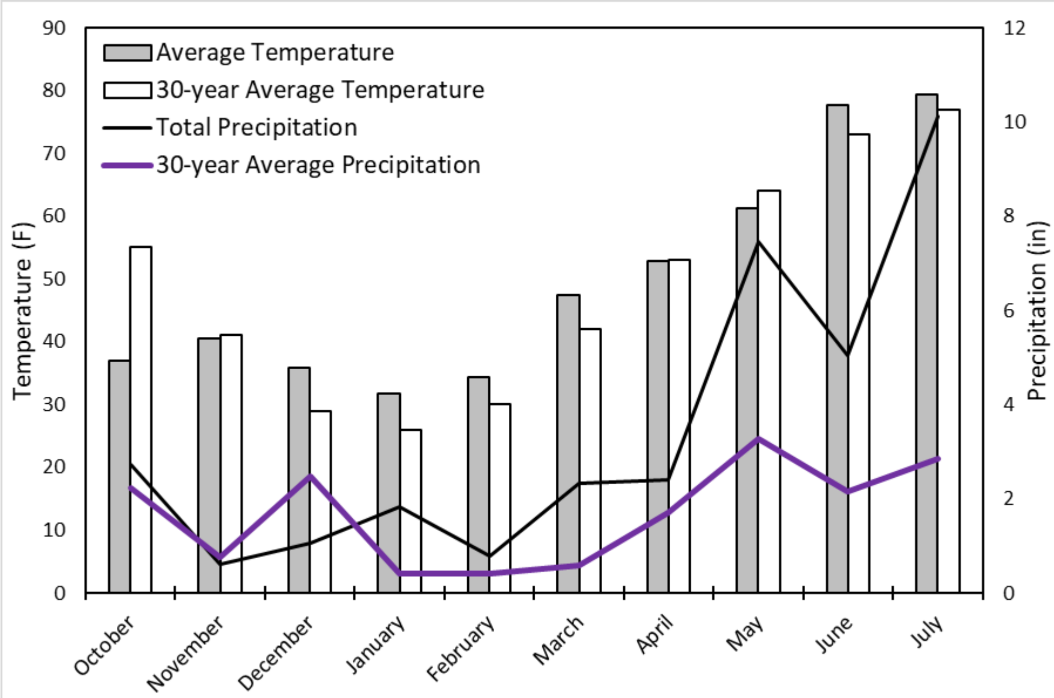

Figure 1. Monthly temperature means and total precipitation throughout 2019–2020 winter wheat growing season, and 30-year historic monthly average temperature and precipitation in Ashland Bottoms, KS.

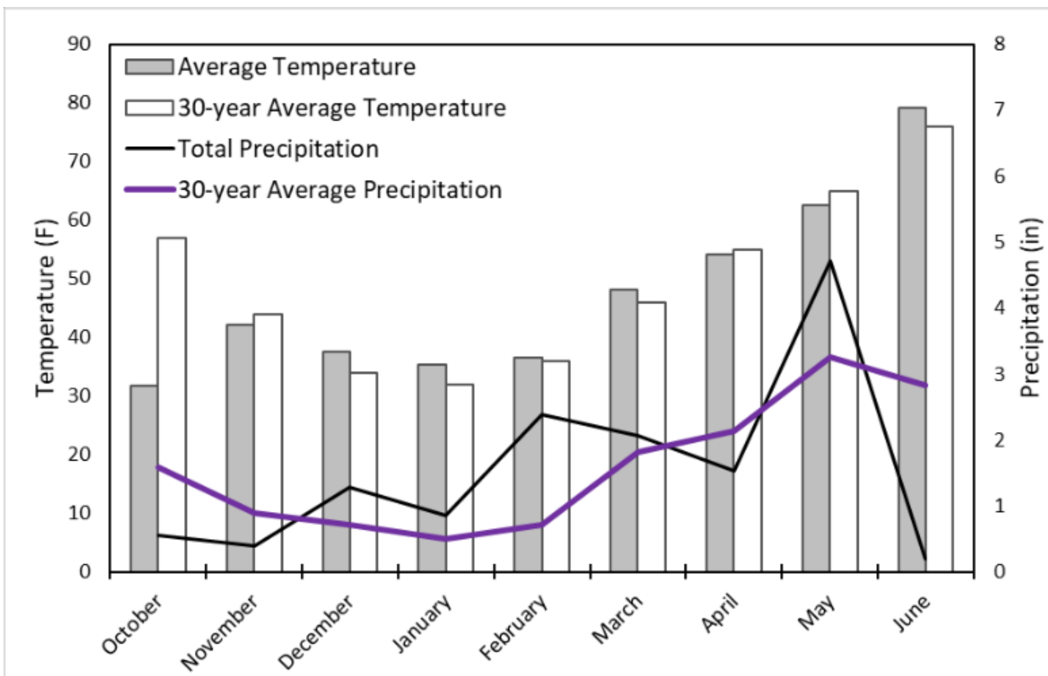

Figure 2. Monthly temperature means and total precipitation throughout 2019–2020 winter wheat growing season, and 30-year historic monthly average temperature and precipitation in Hutchinson, KS.