ADJUSTING N RATE IS THE FIRST STEP IN N MANAGEMENT INTENSIFICATION

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ABSTRACT

Nitrogen (N) management and sowing date are among the leading causes for winter wheat (*Triticum aestivum* L.) yield gap in Kansas. This research aimed to compare the two most common cropping sequences in Kansas (continuous wheat [Ct-Wt] and double-cropping of winter wheat and soybean (*Glycine max* (L.) *Merrill*) [Wt-Sy]) under two N management (standard and progressive) on wheat production. Standard N management consisted of one single broadcast N application as UAN at 80 lbs ac^{-1} at tillering. Progressive N management differed in terms of all 4R components, including N rates which varied year-to-year (80 lbs ac^{-1} in the first year and 67 lbs ac^{-1} in the second year, based on modeled in-season crop conditions), was applied in two timings (tillering and jointing) as UAN with urease and nitrification inhibitors using a streamer bar applicator. Standard and progressive N management had similar responses on grain yield (64 and 67 bu ac^{-1}), shoot biomass (10900 and 10100 lbs ac^{-1}), number of heads ft^{-2} (90 and 81), and seeds size (18000 seeds lb^{-1}) in the first year, in which the total N applied was the same. In the second year, however, the standard N management had greater grain yield (56 vs. 48 bu ac^{-1}) led by higher number of heads ft^{-2} (80 vs. 67) than the progressive treatment. Continuous winter wheat had greater grain yield than Wt-Sy (60 vs. 45 bu ac^{-1}), likely due to a delayed wheat planting date following soybeans. Preliminary findings from this study suggest that N rate trumps the remaining aspects of 4R, suggesting that it should be the first component adjusted to maximize fertilizer use efficiency.

INTRODUCTION

Nitrogen (N) is part of the composition of amino acids (hence, proteins) in plants (Taiz and Zieger, 2010). Synthetic N fertilizers are the most used source to supply N in plants, and it is estimated that 48% of the global population are fed by food grown using synthetic N fertilizer (Smil, 2004). Increasing food production while respecting environmental concerns requires efficient use of resources due to finite sources to produce synthetic fertilizers (Fischer et al., 2012). Simultaneously, increasing yields to narrow yield gaps is also essential to supply the increasing food demand. Yield gap for winter wheat (*Triticum aestivum* L.) in Kansas is estimated at c.a. 50% (Lollato et al., 2017), and poor N management are among the leading issues causing the gap (Lollato et al., 2019a; de Oliveira Silva et al., 2020; Jaenisch et al., 2021). Still, simply applying more fertilizer may not be the answer due to increasing environmental concerns. The fertilizer industry developed the 4R Nutrient Stewardship guidelines to improve fertilizer management practices worldwide. The approach includes the Right Rate (i.e., enough amount to maximize production), Right Source (i.e., matching fertilizer to the cropping system and its potential losses), Right Placement (i.e., minimize N losses through more precise application), and Right Timing (i.e., nutrients should be available to match the crop's demand) (Johnston and Bruulsema, 2014).

Around 51% of the winter wheat produced in Kansas is monoculture, and 30 to 44% are grown after soybean (*Glycine max* (L.) *Merrill*) depending on region within the state (Jaenisch et al., 2021). Winter wheat grown after soybean is usually sown after the end of the optimum sowing window, resulting in lower yields likely due to drier soils and fewer degree days accumulation (Munaro et al., 2020; Jaenisch et al., 2021). Crop management practices must be adjusted according to previous crop and sowing date for winter wheat to minimize yield losses due to late sowing (Staggenborg et al., 2003). While information on management adjustments for late sown winter wheat exists in terms of seeding rate and N rate (Bastos et al., 2020; Staggenborg et al., 2003), little is known about adjustments of the entire 4R system under these conditions.

Considering that little is known about the interaction between two of the major factors affecting winter wheat yield in Kansas (i.e., N management and sowing date – as affected by cropping system), the objective of this research was to evaluate the effect of improved N management through manipulation of the 4R and its interaction with common cropping sequences for winter wheat in Kansas.

MATERIAL AND METHODS

Field Set-Up

A rainfed field experiment was conducted during the 2019-2020 and 2020-2021 winter wheat growing seasons at the Agronomy Farm in Ashland Bottoms, northeast KS (fine-silty, mixed, mesic Cumulic Haplustoll). The winter wheat variety Zenda was planted both years with a seeding rate of 90 lbs ac^{-1} when sowed at optimum date and 120 lbs ac^{-1} when sowed after soybean, drilled at 7.5 in row spacing using a 9-row Great Plains 506 no-till drill on 2000 ft^{2} plots (40 ft wide x 50 ft long). Diammonium phosphate (DAP 18-46-0) starter fertilizer was used in the plots at 50 lbs ac^{-1} in both years. In the first year, winter wheat was sowed and harvested on October 24 and July 7, respectively. In the second year, the continuous winter wheat cropping sequence was sowed on October 15 (optimum planting date), and winter wheat after soybean was sowed on November 7 (later planting date); both were harvested on June 6. Pests, weeds, and diseases were monitored and controlled regularly so they were not limiting factors in this experiment. The center of each plot was harvested for grain (300 ft^{2} area) using a Massey Ferguson XP8 small-plot, self-propelled combine.

Experimental Design

A split-plot design with four replications was conducted with two cropping sequences (whole plot) under two N management (subplot). Crop sequences were continuous winter wheat (Ct-Wt) and double-cropping of winter wheat and soybean (Wt-Sy). Nitrogen management hereafter will be defined as Standard and Progressive. Each N management (standard vs. progressive) differed in application timing (single vs. split N application), placement (broadcast vs. streamer bar applicator), source (the absence [standard] or presence [progressive] of urease/nitrification inhibitors), and N rate (80 lbs ac^{-1} vs. in-season N recommendation based on seasonal conditions).

The standard N management consisted of one single application at Zadoks 30 of 80 lbs ac^{-1} of N (UAN 28-0-0), broadcasted with flat fan nozzles. The progressive N management was a split N application during two wheat growth stages (Zadoks 30 and Zadoks 32) using a more precise applicator (streamer bar) and with the presence of urease and nitrification inhibitors (Centuro, Koch Agronomic Services Co., Wichita, KS 67220, at 23 L per ton of fertilizer; and Agrotain Plus SC, Koch Agronomic Services Co., Wichita, KS 67220, at 14 L per ton of fertilizer) along with UAN (28-0-0). The rate of N applied in the progressive treatment varied year-to-year based on in-season crop forecasting models that informed management decisions using novel cropland observation nodes, through monitoring crop conditions and water balance. In the first year, the progressive N management had two N applications of 40 lbs ac^{-1} of N each, while in the second year, the first application was 40 lbs ac^{-1} of N and 27 lbs ac^{-1} of N in the second application (i.e., 13 lbs ac^{-1} of N less than in the first year).

Measurements & Statistical Analysis

Soil fertility levels were based on the first 0 to 6 in depth with a soil pH of 6, and 14.3 and 317 ppm levels of Mehlich-3 extractable phosphorus and potassium, respectively. Shoot biomass was collected from a representative 2.1 ft^2 plot area before harvest, in which total biomass weight, number of heads, and one seeds size were measured. Weather data was retrieved from weather monitoring station from the Kansas Mesonet (http://mesonet.k-state.edu/) in Ashland Bottoms, KS, which provided precipitation and evapotranspiration (grass ET_o).

Statistical analysis was performed using the PROC GLIMMIX procedure in SAS v. 9.4 (SAS Inst. Inc., Cary, NC). Nitrogen, cropping sequence, and replication were treated as a fixed effect, and years were analyzed separately due to the significant main effect of year. Cropping sequence was not included in the model in the first year as it was the establishment year of the study and crop sequences were not yet in place.

RESULTS

Weather Conditions

The 30-year normal average precipitation during winter wheat growing season (Oct-July) is 26-in in Ashland Bottoms, KS. In this study, total precipitation during winter wheat growing season was historically below average in both years. Precipitation was 22-in and 18-in in the first and second year, respectively. In the second year, the Wt-Sy rotation received 1.5-in less rainfall than Ct-Wt (16.5 vs. 18-in, respectively) because of a later sowing date. Seasonal ET_o was 29-in and 30-in in the first and second year, respectively, except for Wt-Sy rotation, which had a 24.5-in ET_o (5.3-in less than Ct-Wt) in the second year again due to the later sowing date. In both years, water supply was lower than ET_o.

Grain Yield

Grain yield results for the first and second year are shown in Table 1 and 2, respectively. Winter wheat grain yield ranged from 58 to 72 bu ac^{-1} and from 40 to 66 bu ac^{-1} in the first and second year, respectively. Nitrogen management had similar grain yield in the first year (64 and 67 bu ac^{-1} for standard and progressive, respectively), and standard N management had significantly greater yield than progressive in the second year (55 vs. 48 bu ac^{-1}). In the second year, Ct-Wt had greater yield than Wt-Sy (60 vs. 45 bu ac^{-1}).

Biomass, number of heads, and seeds size

Results for the first and second year are shown in Table 1 and 2, respectively. In the first year, N management did not induce differences in shoot biomass, number of heads ft^{-2}, and seeds size. In the second year, only cropping sequence effect was significant on shoot biomass, in which Ct-Wt had greater shoot biomass than Wt-Sy (9700 vs. 7600 lbs ac^{-1}, respectively). In the second year, Ct-Wt and standard N had greater number of heads ft^{-2} than Wt-Sy and progressive N (78 vs. 67, and 80 vs. 66 heads ft^{-2}, respectively). The N management was the only significant effect on seeds size in the second year, in which progressive N had greater seeds size than standard N (16650 vs. 18000 seeds lb^{-1}, respectively).

DISCUSSION

Higher yields in the first year were likely due to greater precipitation than in the second year (>4-in greater) and lower ET_o. In the first year, N management treatments differed in application timing, placement, and absence or presence of N inhibitors, but the total N applied in the crop was the same (80 lbs ac^{-1}). Although there was a numerical advantage to the progressive N treatment when rates were the same (3 bu ac^{-1}), this difference was not statistically significant. In the second year, the total N rate also differed between treatments (80 vs. 67 lbs ac^{-1}). This result shows that, although progressive N management had more precise N application and was less likely to N losses, the total N applied still plays a major role for grain yield response (de Oliveira Silva et al., 2020). The yield component modulated here was number of heads ft^{-2}, likely due to more tiller production and maintenance in the high N treatment, which was clearer when the treatments responses were not different when the same amount of N was applied. Despite higher yields, the standard N management had lower seeds size than progressive. This is common in wheat response to N rate studies, as a greater N rate will lead to more kernels ft^{-2} and thus to a greater proportion of distal kernels that are naturally smaller. This also confirms that heads ft^{-2}, acting as a coarse regulator of wheat yield, influences yield more than kernel weight which is a fine regulator of wheat yield (Slafer et al., 2014). Finally, these results also show that modeling for crop yield forecasting to dictate N rates is very incipient, as clearly recommendations for 67 lbs N ac^{-1} were suboptimal. Because the optimal N rate depends on yield environment (Lollato et al., 2019b), more efforts are needed to improve prediction of yield environment to fine tune N rate recommendations.

The difference in grain yield regarding cropping sequences is likely due to optimum planting date for winter wheat under the Ct-Wt (Thompson et al., 1996), and sowing date has shown to be the most important variables affecting grain yield in the U.S. central Great Plains (Munaro et al., 2020; Jaenisch et al., 2021). On Wt-Sy rotation, wheat is not sowed until soybean harvest, which falls in early November, resulting in a later sowing date for eastern Kansas. Consequently, and the critical period for grain number determination is shortened and grain filling is hastened, which translates into less shoot biomass production (Gastal et al., 2015) and fewer heads ft^{-2}.

CONCLUSIONS

Standard N management had similar results as the progressive N management when the same rate of N was applied to the crop. However, when under higher N rates, the standard management had greater yield, suggesting that, although the application of 4R nutrient guidelines is ideal, there are components within the 4R that play a major role. In this case, N rate trumped N application timing, placement, and source when these were applied at a lower N rate. Grain yield was dictated not by intensifying N application but by the scarcest resource (total N applied). Therefore, N management intensification should be applied only when N rates are appropriate.

Table 1. Effect of nitrogen (N) management on winter wheat grain yield, shoot biomass, number of heads ft^{-2}, and seeds size at Ashland Bottoms, KS, during 2019-2020 growing season.

N management[a]	Yield ($bu\ ac^{-1}$)	Biomass ($lbs\ ac^{-1}$)	Number of heads ft^{-2}	Seeds size ($seeds\ lb^{-1}$)
Standard	64 ± 1†	10900 ± 400	90 ± 4	18000 ± 150
Progressive	67 ± 1	10100 ± 400	81 ± 4	18000 ± 150

† Standard error of the mean;

[a] N-management: Standard (single N-application using broadcasting applicator with the absence of N-inhibitors at 80 lbs ac^{-1} of N); and Progressive (split N-application into two timings using streamer bars with the presence of N-inhibitors at 80 lbs ac^{-1} of N).

Table 2. Effect of nitrogen (N) management and cropping sequence (crop. seq.) on winter wheat grain yield, shoot biomass, number of heads ft^{-2}, and seeds size at Ashland Bottoms, KS, during 2020-2021 growing season.

Crop. seq[a]. > N management[b]	Ct-Wt	Wt-Sy	N mean
	Yield ($bu\ ac^{-1}$)		
Standard	64 ± 1†	45 ± 1	54.5
Progressive	55 ± 1	40 ± 1	47.5
Crop seq. mean	59.5	42.5	-
	Biomass ($lbs\ ac^{-1}$)		
Standard	10200 ± 400	8200 ± 400	9200
Progressive	9000 ± 400	7000 ± 400	8000
Crop seq. mean	9700	7600	-
	Number of heads ft^{-2}		
Standard	87 ± 3	73 ± 3	80
Progressive	70 ± 3	62 ± 3	66
Crop seq. mean	78	67	-
	Seed size ($seeds\ lb^{-1}$)		
Standard	17650 ± 1500	17450 ± 1500	17550
Progressive	16650 ± 1500	17050 ± 1500	16850
Crop seq. mean	25975	17250	-

† Standard error of the mean;

[a] Ct-Wt = continuous wheat; Wt-Sy = double-cropping of winter wheat and soybean;

[b] N-management: Standard (single N-application using broadcasting applicator with the absence of N-inhibitors at 80 lbs ac^{-1} of N); and Progressive (67 lbs ac^{-1} of N split into two timings using streamer bars with the presence of N-inhibitors).

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