Long-Term Tillage and Nitrogen Fertilizer Rates Effect on Grain Yield and Nitrogen Uptake in Dryland Wheat and Sorghum Production

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Summary

Winter wheat and grain sorghum rotation is a common cropping system in dryland environments in western Kansas. A long-term field experiment (started in 1975) was conducted in Hays, KS, to examine interaction effects of tillage and nitrogen (N) fertilizer rates on wheat and grain sorghum yields, protein content, N uptake, and N use efficiency (NUE). The experimental design was a split-split-plot arrangement of rotation, tillage, and N application treatments in a randomized complete block design. The main plots were the crop phase (winter wheat, grain sorghum, or fallow), sub-plots were three tillage systems (conventional tillage (CT), reduced tillage (RT), and no tillage (NT)). The sub-sub-plots were four N rates (0, 20, 40, and 60 lb/a), which were modified in fall 2014 to 0, 40, 80, and 120 lb/a. Results showed year-to-year variability in winter wheat and grain sorghum responses to tillage practices and N fertilizer rates. Competition from herbicide-tolerant grass weeds reduced winter wheat yields in NT treatments in dry years but performed similarly to tillage treatments in wet years. However, grain sorghum yields with NT were greater or similar to CT or RT in most years of the study. Grain yields for both crops increased with N fertilizer application rates. Decreasing tillage intensity did increase wheat grain protein concentration only in 2018, which was relatively dry. Applying N fertilizer improved protein concentration, but the effect was more pronounced in years with less than average growing season precipitation. However, N use efficiency decreased at a higher N fertilizer rate particularly in dry years for both crops.

Introduction

The United States Great Plains region is critically important in the production of wheat and sorghum. The adoption of conservation tillage practices, such as no tillage (NT) and reduced tillage (RT) has led to reduced erosion, increased soil organic matter (SOM), and increased precipitation storage in the Great Plains (Logan et al., 1991; Thomas et al., 2007; Triplett and Dick, 2008). Wheat-fallow (W-F) or wheat-summer crop-fallow are the most used wheat production systems in the Great Plains (Anderson, 2005). Grain sorghum produced greater grain yield than the corn crop under the dryer and warmer climate growing conditions because the sorghum crop remained inactive during the period of severe water stress and resumed growth when favorable conditions reappeared (Leonard and Martin, 1963).

The increased use of N fertilizer has resulted in reductions in yield gaps in the major cereal crops (Dobermann and Cassman, 2004). Applying N fertilizer increases crop yield and enhances drought resistance of crops in semiarid regions (Ding et al., 2018). However, environmental ramifications (e.g. greenhouse gas emission, water pollution, soil quality degradation, and accumulation of soil NO_3-N in soil profile) as well as lower N use efficiency (NUE) are caused by excessive application of N fertilizer (Malhi et al., 1996; Davidson 2009; Morell et al., 2011; Reay et al., 2012; Zhou et al., 2016). Nitrogen is commonly applied to grain crops because it's one of the most limiting nutrients in crop production and heavily influences the sustainability and economic viability of agriculture systems worldwide (Delgado et al., 2010; Grahmann et al., 2013). Nitrogen is an essential nutrient and required in large amounts by crops to optimize yield and water use efficiency (Delgado et al., 2010; Fageria, and Baligar, 2005). Further, Guarda et al., (2004) showed both grain yield and quality are directly related to the N uptake and effective partition by crops.

Long-term research efforts are critically needed to identify superior soil and nutrient management practices for the limited water environments of the Great Plains region. In semi-arid regions, intensifying the frequency of cropping systems has been used as another conservation approach, and has led to greater yield performance (Halvorson et al., 2001). Wheat yields have been shown to match or exceed those of conventional tillage (CT) systems, when NT and RT practices have been implemented for ten years or longer (Pittelkow et al., 2015). However, integrating these practices in some systems has led to a reduction in crop quality and yield, compared with CT practices. This has been attributed to the effects that NT has on N dynamics (Lundy et al., 2015; Pittelkow et al., 2015; and Ruisi et al., 2016). Previous studies reported that the residual NO_3-N within the 0 to 5 ft soil profile is higher with CT and RT compared to NT (Halvorson et al., 2001), particularly with more precipitation. The NT system would be a promising technique of reducing residual soil NO_3-N available for leaching compared to CT and RT. After 5 years, measurement of soil under various tillage practices showed available N (NO3-N) was higher under NT compared to different tillage plots within 0 to 12 inch (López-Fando and Pardo, 2009) as a dramatic change occurred within 0 to 2.5 inch soil depth. Also, after 16 years of CT and NT on a winter wheat-summer fallow experimental plots in Colorado, available N (NO_3-N) was higher in the upper one inch under NT compared to tilled plots (Tracy et al., 1990). In another study in the semiarid region of Spain, significantly greater available N was found in soils under NT compared to RT or CT (López-Fando et al., 2007). It is important to use appropriate tillage practices that avoid the degradation of soil structure, maintain crop productivity, and provide a sustainable agriculture system.

Adoption of conservation tillage practices (NT or RT) can be used to improve soil properties (physical, chemical, and biological) for the benefit of the environment and soil productivity (Aina, 2011). For example, conservation tillage can increase soil water storage (Anderson, 2009; López-Fando and Pardo, 2009) and improve water and fertilizer use efficiencies (Triplett and Dick, 2008) compared to traditional tillage systems. Winter wheat has a relatively high N demand, and has one of the lowest NUE compared to other cereals (Schlegel et al., 2005; Muurinen et al., 2007). Our objective for this work was to investigate the effects of tillage and N fertilizer rates on wheat and grain sorghum yields, protein content, N uptake, and use efficiency.

Procedures

This research was conducted utilizing long-term experimental plots initiated in the fall of 1965 at the Kansas State University Agricultural Research Center near Hays, KS (38°86′ N, 99°27′ W, 2000 ft elevation) to investigate tillage intensity (CT, RT, and NT) on grain yields in a winter wheat-grain sorghum-fallow crop production system. The soil at the study site is a Harney silt loam (fine, montmorillonite, mesic Typic Agriustoll; USDA Soil Taxonomy). The experiment was modified in 1975 and has since been managed as a split-split-plot arrangement of crop phase, tillage, and N application rates in a randomized complete block design with four replications. Each phase of the crop rotation and tillage are present in each block in every year of the study. The main plots were the crop phase, which consisted of winter wheat, grain sorghum, or fallow (sorghum stubble). Tillage practice was the subplot factor and N rates were the sub-subplot factor. Each block (198 ft × 100 ft) contained the three tillage treatments (CT, RT, and NT plots). Each tillage practice (67 ft × 100 ft) was subdivided by six sub-plot factors (11 ft × 100 ft), and subplots were assigned the four N application rates (0, 20, 40, and 60 lb N/a) with two unfertilized alleys between tillage treatments. Nitrogen rates were increased starting in the fall of 2014 to 0, 40, 80, and 120 lb N/a. The entire study site has not been amended with lime or phosphorus since its establishment in 1965.

The data on grain yield for winter wheat and sorghum have been recorded from 2015 to 2018; however, the plots and treatment were maintained throughout the study period. Total aboveground biomass for winter wheat (only) was determined in 2015, 2016, 2017, and 2018 by cutting approximately 6 ft^2. Both grain and biomass samples were finely ground, and analyzed for N concentration and carbon content by dry combustion using a LECO CN analyzer (LECO Corporation, St. Joseph, MI). The amount of N removed in the grain was computed by multiplying N concentration by grain yield. Nitrogen use efficiency (NUE) was determined as N mass in grain/N fertilizer rate applied.

Data for winter wheat and grain sorghum yield from 2015 to 2018 were analyzed for variance (ANOVA) using PROC MIXED procedure in SAS (v. 9.4, SAS Inst. Inc., Cary, NC), and the Tukey's Honest Significant Difference was used for mean comparisons with an alpha (α) of 0.05.

Results

Total precipitation amounts after dormancy in winter wheat were substantially below average during the 4-year study period. However, total precipitation in May was generally above average for all of the study years (Table 1). Rainfall during this period is important for normal crop development in winter wheat. Total season precipitation was highest in 2018 and above average for all study years except in 2015, which experienced below average total precipitation during the grain sorghum season. The low precipitation amounts in March and April of 2018 could have a significant impact on winter wheat yields. The long term average total precipitation during the fallow period is 21 inches for winter wheat and 20 inches for grain sorghum. During this study, total precipitation during the fallow period was above average except for the fallow periods preceding the 2016 winter wheat and 2018 grain sorghum crops (Table 1). The long term average precipitation during the growing season is 14 inches for winter wheat and 13 inches for sorghum. Except for 2015, precipitation amounts during the growing seasons were above normal for both crops (Table 1).

Winter wheat yield was significantly affected by year × tillage interaction (Table 2). Grain yield with CT was greatest in most years of the study. Both RT and NT had lower yield when compared to CT in 2015 and 2018, and 2017 for RT only. However, grain sorghum yields showed less significant variation among tillage systems over the 4-year study—with the exception of 2016 when NT had the highest yield compared to CT and RT (Figure 1B). Tillage × year interaction had an effect on winter wheat and grain sorghum yields. Winter wheat yield increased with increasing N fertilizer application rate compared to control (Figure 1C). Similarly, there was a significant difference in sorghum grain yields with varying fertilizer application rates in 2016, 2017, and 2018. Applying N fertilizer had no significant effect on grain sorghum yield in 2015 (Figure 1D). Regardless of N application rate, winter wheat yields in 2018 were lower than in 2015, 2016, and 2017. This was possibly due to less precipitation amounts in the growing season (Table 1). Nevertheless, greater precipitation amounts from May through October of 2018 increased grain sorghum yield compared to the remaining years of the study (Figure 1D).

Grain N concentration was significantly affected by tillage × year interaction. The 2018 winter wheat grain N concentration was the exception, as it was not different among tillage practices (Figure 2A). Grain N concentration was highest with less intensive tillage (RT and NT) treatments compared to CT for winter wheat. However, in grain sorghum, the tillage (CT and RT) treatments had more N concentration in 2015 compared to NT. There was no difference in grain N concentration among tillage practices in the 2016 and 2018 growing seasons for grain sorghum (Figure 2 B). On the other hand, the grain N concentration was greatest with the highest N fertilizer rates (120 lb N/a) across the 4 years of the study for both crops (Figure 2C and D).

There was a significant effect of tillage practices on winter wheat N removal in years 2015, 2017, and 2018, and in 2015 and 2017 for grain sorghum (Figure 3A and B, respectively). However, N removal was not different among tillage practices in 2016 for winter wheat and 2018 for grain sorghum. Across the years, the CT practice had relatively equal grain N removal rates compared to other tillage practices for grain crops (Figure 3A and B). Increasing N application rate did increase N removal in both winter wheat and grain sorghum (Figure 3C and D). This was expected because applying N fertilizer increases grain yield and N concentration in both crops.

The grain NUE (lb/lb) in terms of partial N balance was significantly affected by tillage practices in both 2017 and 2018. Winter wheat NUE was highest with the CT and RT compared to NT in both years (Figure 4A). For grain sorghum (Figure 4B), the grain NUE was also significantly affected by tillage practices. The effect of tillage practices did not show an obvious trend. For example in 2015, CT showed significantly greater

NUE compared to NT, but in 2016 NT had the greatest NUE compared to CT or RT. Tillage had no effect on NUE in 2018 (Figure 4B).

There was a significant N fertilizer application rates × year effect on NUE for both crops. The NUE was greatest when N was applied at 40 lb N/a compared to 80 and 120 lb/a for winter wheat (Figure 4C) and grain sorghum (Figure 4D). Generally, increasing N application rates decreased the grain NUE, indicating some of the applied N remaining in the soil may be lost through leaching, volatilization, and deep percolation.

For winter wheat, the grain protein content was not significantly different among tillage practices in 2015, 2016, and 2017. However, in 2018, increasing tillage intensity significantly reduced protein content. This is possibly due to a dilution effect from greater wheat yields, with CT exhibiting the greatest yields and NT exhibiting the lowest yields (Figure 5A). Nitrogen fertilizer application rates × year interaction had an effect on protein content. This interaction occurred because of significantly lesser protein content obtained in 2017. In general, protein content significantly increased with N fertilizer application (Figure 5B). Across the 4-year study, applying N at 120 lb N/a resulted in the highest protein percent content.

For grain sorghum, the grain protein content was highest in 2018 compared to the remaining years of the study regardless of tillage practice or N fertilizer application rates (Figure 5C and D). The grain protein content was highest relatively with CT compared to other tillage practices and increased at the highest N fertilizer rate (120 lb N/a) when compared to other N fertilizer application rates.

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Table 1. Total monthly precipitation and growing season periods of winter wheat and grain sorghum of 404 plots at Hays, KS

	Precipitation				
	2015	2016	2017	2018	LTA†
	---	---	in	---	---
January	0.46	0.68	1.25	0.45	**0.54**
February	0.71	0.70	0.10	0.15	**0.74**
March	0.09	0.56	1.50	0.77	**1.66**
April	0.96	7.46	7.83	0.74	**2.31**
May	6.44	3.04	4.58	4.86	**3.21**
June	0.76	3.44	3.82	3.92	**2.89**
July	4.11	3.45	1.53	7.82	**3.64**
August	0.46	3.78	3.08	5.60	**3.01**
September	0.42	2.08	2.17	3.44	**1.97**
October	1.75	0.66	1.96	3.09	**1.53**
November	1.83	1.18	0.24	0.46	**0.93**
December	1.77	0.57	0.04	1.68	**0.72**
Total	**19.76**	**27.60**	**28.10**	**32.98**	**23.15**
J to M§	**8.66**	**12.44**	**15.26**	**6.97**	**8.46**
Growing season period of winter wheat					
PF§	24	15	29	28	**21**
PG§	12	21	21	13	**14**
PT§	**36**	**36**	**50**	**41**	**35**
Growing season period of grain sorghum					
PF§	22	23	27	16	**20**
PG§	8	13	13	24	**13**
PT§	**30**	**36**	**40**	**40**	**33**

†Long-term average (LTA) (43 years, 1975 to 2018).
§Precipitation during fallow (PF), growing season (PG), and total precipitation (PT).
January to May (J to M).

Table 2. Analysis of variance summary of the effects of year (YR), tillage (TILL), N fertilizer rate (NR), and their interactions on grain yield (lb/a), N concentration (N conc., %), N removed (NR, lb/a), nitrogen use efficiency (NUE, lb grain/lb N applied), and grain protein content (%) for winter wheat yield and grain sorghum in Hays, KS

Treatment effect	Yield	N conc.	NR	NUE	Protein
Winter wheat[‡]					
YR	**<.0001**	**<.0001**	**<.0001**	**0.0001**	**<.0001**
TILL	**0.0002**	0.4919	**0.0003**	**0.0017**	0.5268
YR × TILL	**0.0213**	**0.0077**	**0.0078**	**0.0145**	**0.0077**
NR	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
YR × NR	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
Till × NR	0.0824	0.5295	0.9432	0.5193	0.5317
YR × TILL × NR	0.1464	0.4947	0.2930	0.6595	0.4927
Grain sorghum[‡]					
YR	**<.0001**	**<.0001**	0.2251	0.2251	**<.0001**
TILL	**0.0006**	0.0629	0.2102	0.2102	0.0585
YR × TILL	**<.0001**	**0.0214**	**0.0203**	**0.0203**	**0.0202**
NR	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**
YR × NR	**<.0001**	**<.0001**	0.3813	0.3813	**<.0001**
Till × NR	0.5508	0.8287	0.9414	0.9414	0.8152
YR × TILL × NR	0.6053	0.9869	0.9696	0.9696	0.9864

[‡]*P-value* of treatment effects in bold are significant at $P < 0.05$.

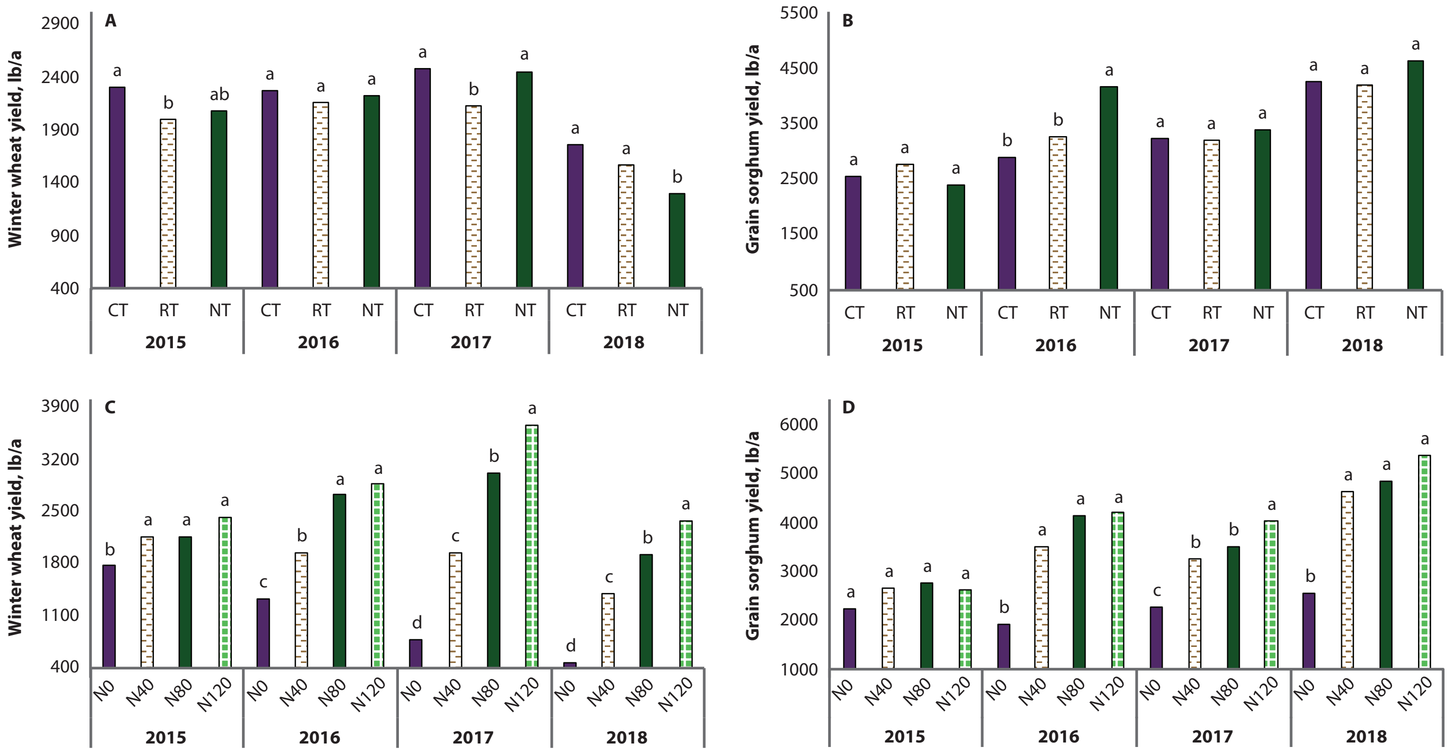

Figure 1. Grain yield (lb/a) as affected by tillage (conventional tillage, CT; reduced tillage, RT; and no tillage, NT) and nitrogen (N) fertilizer rates (0, 40, 80, and 120 lb/a) for winter wheat (A) and (C) respectively, and grain sorghum (B) and (D), respectively over four growing seasons (2015–2018) at Hays, KS. Means followed by the same letter(s) within a given year are not different (*P* ≥ 0.05).

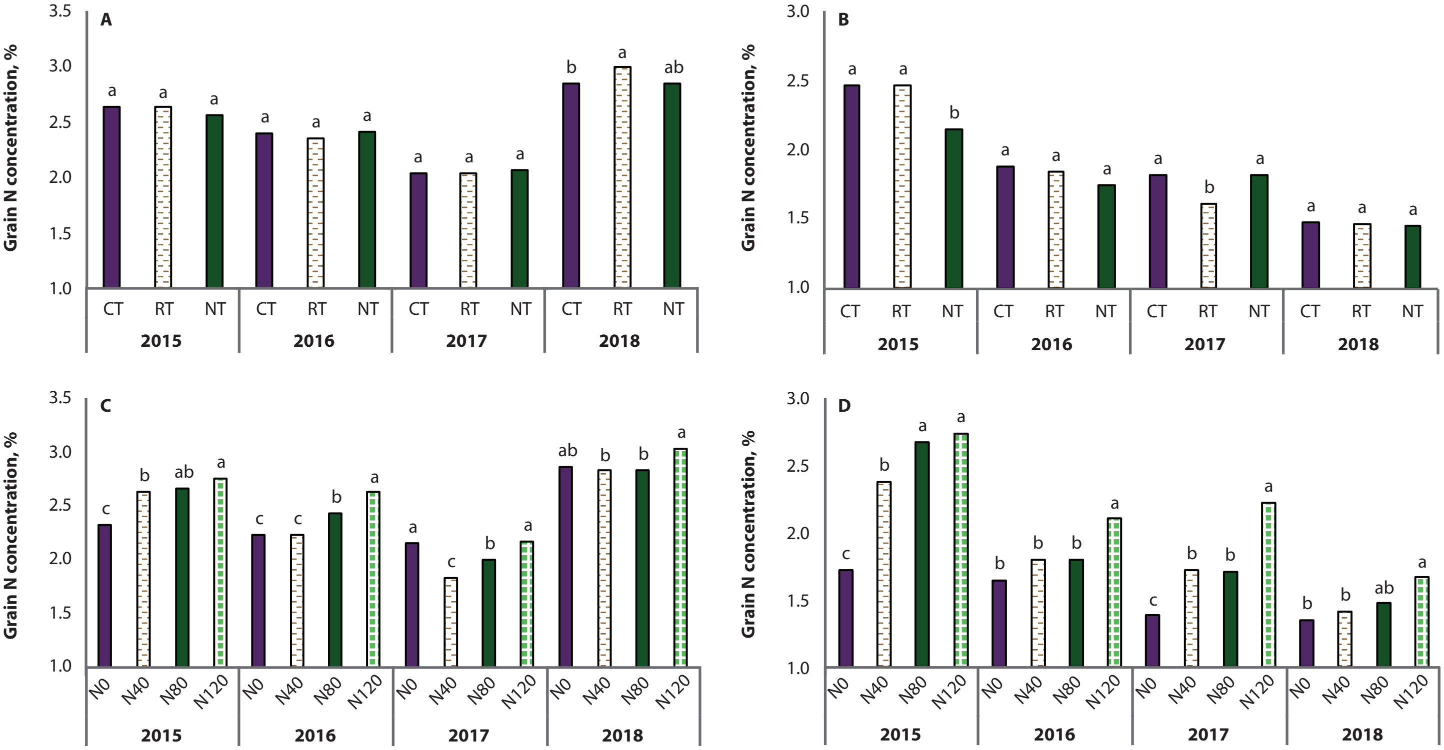

Figure 2. Grain nitrogen (N) concentration (%) as affected by tillage (conventional tillage, CT; reduced tillage, RT; and no tillage, NT) and N fertilizer rates (0, 40, 80, and 120 lb/a) for winter wheat (A) and (C) respectively, and grain sorghum (B) and (D), respectively over four growing seasons (2015–2018) at Hays, KS. Means followed by the same letter(s) within a given year are not different ($P \geq 0.05$).

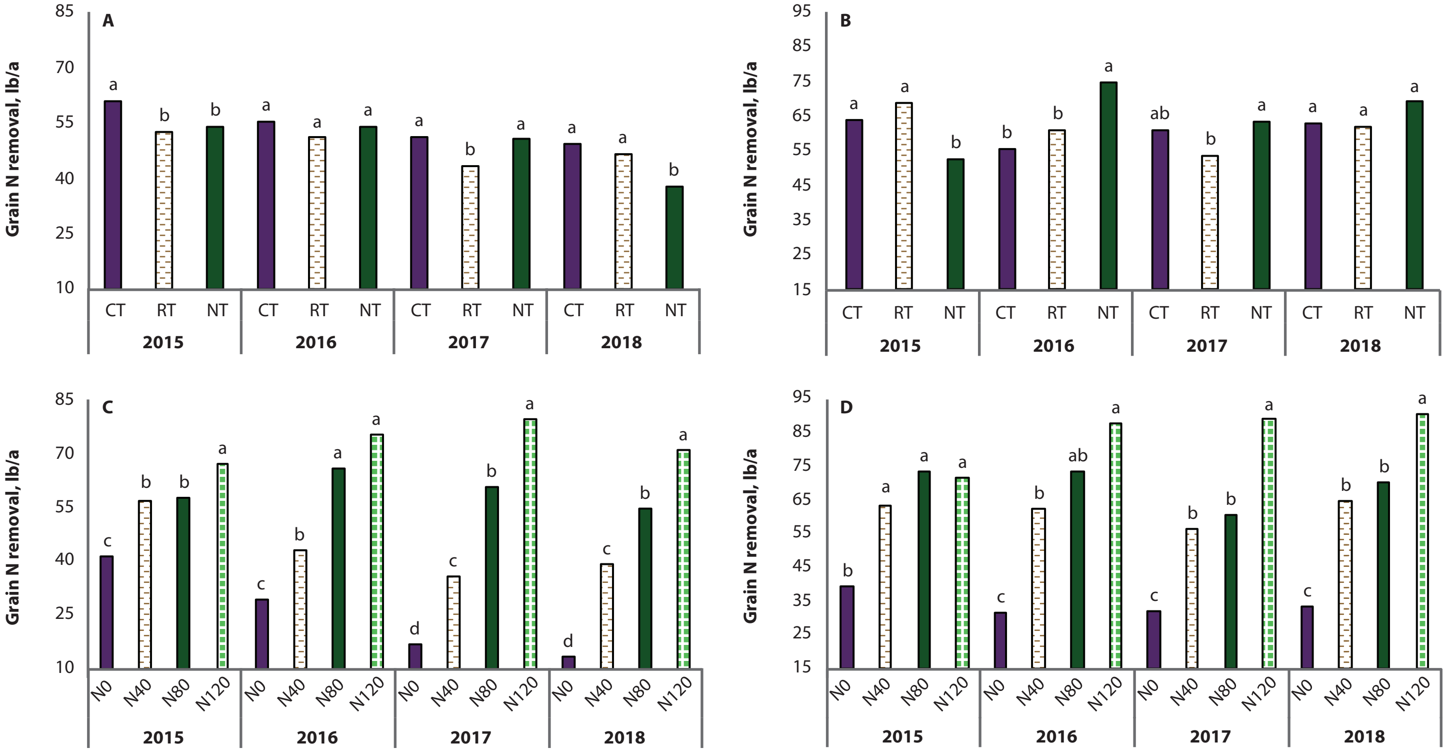

Figure 3. Grain nitrogen (N) removal (lb/a) as affected by tillage (conventional tillage, CT; reduced tillage, RT; and no tillage, NT) and N fertilizer rates (0, 40, 80, and 120 lb/a) for winter wheat (A) and (C) respectively, and grain sorghum (B) and (D), respectively over four growing seasons (2015–2018) at Hays, KS. Means followed by the same letter(s) within a given year are not different (*P* ≥ 0.05).

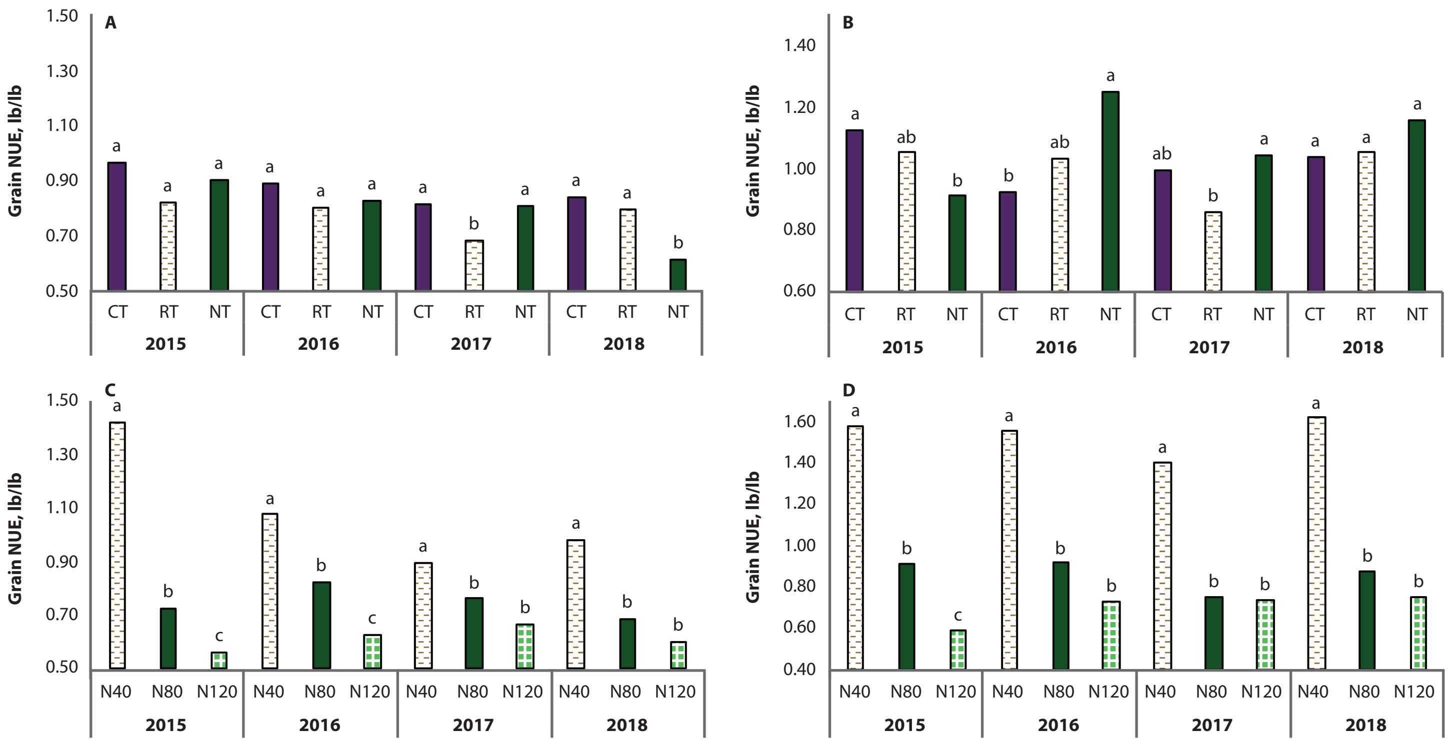

Figure 4. Nitrogen use efficiency (NUE) (lb/lb) as affected by tillage (conventional tillage, CT; reduced tillage, RT; and no tillage, NT) and N fertilizer rates (0, 40, 80, and 120 lb/a) for winter wheat (A) and (C) respectively, and grain sorghum (B) and (D), respectively over four growing seasons (2015–2018) at Hays, KS. Means followed by the same letter(s) within a given year are not different (*P* ≥ 0.05).

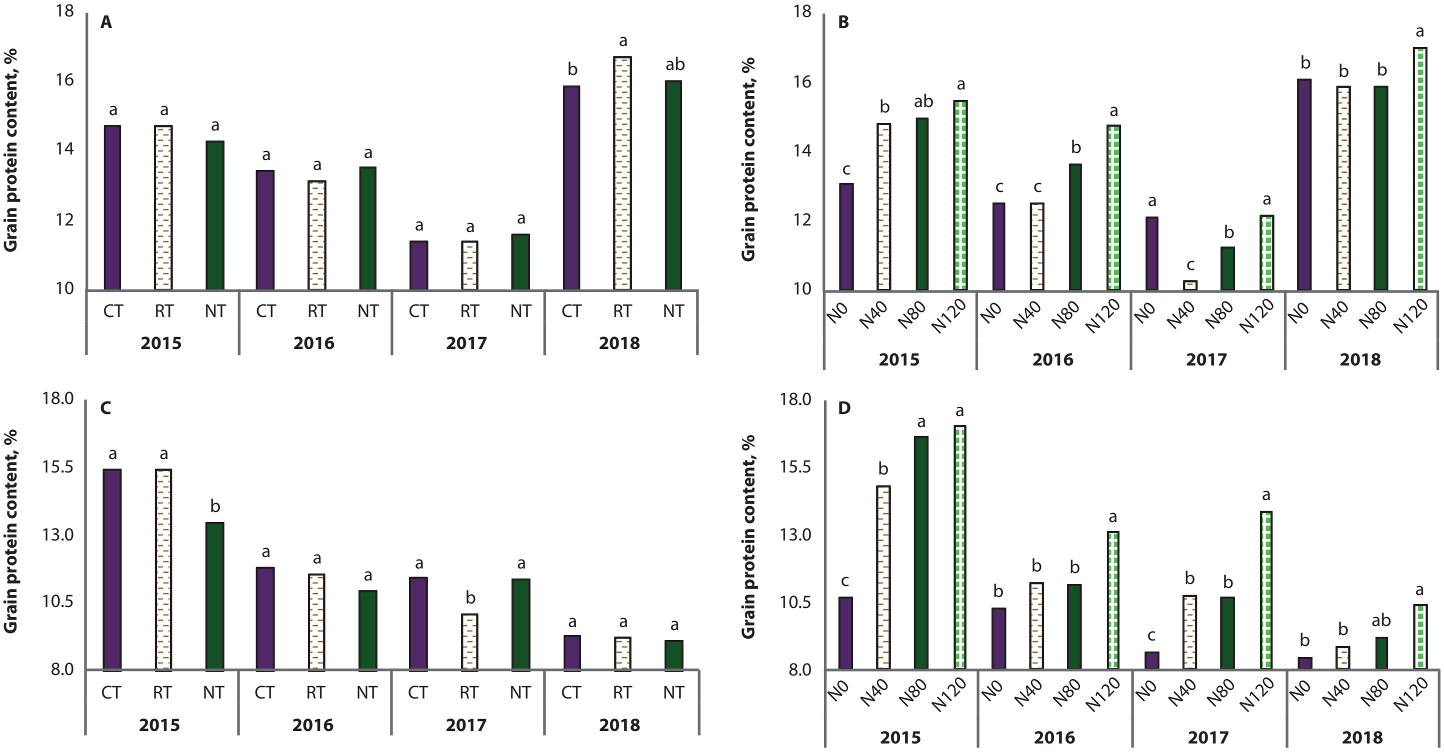

Figure 5. The grain protein content (%) as affected by tillage (conventional tillage, CT; reduced tillage, RT; and no tillage, NT) and nitrogen (N) fertilizer rates (0, 40, 80, and 120 lb/a) for winter wheat (A) and (B), respectively, and for grain sorghum (C) and (D), respectively over four growing seasons (2015–2018) at Hays, KS. Means followed by the same letter(s) within a given year are not different ($P \geq 0.05$).