

2019

## Crop Yield and Yield Stability as Affected by Long-Term Tillage and Nitrogen Fertilizer Rates in Dryland Wheat and Sorghum Production Systems

M. Majrashi  
*Kansas State University*, majrashi@k-state.edu

A. K. Obour  
*Kansas State University*, aobour@ksu.edu

C. J. Moorberg  
*Kansas State University*, moorberg@ksu.edu

Follow this and additional works at: <https://newprairiepress.org/kaesrr>



Part of the [Agronomy and Crop Sciences Commons](#)

---

### Recommended Citation

Majrashi, M.; Obour, A. K.; and Moorberg, C. J. (2019) "Crop Yield and Yield Stability as Affected by Long-Term Tillage and Nitrogen Fertilizer Rates in Dryland Wheat and Sorghum Production Systems," *Kansas Agricultural Experiment Station Research Reports*: Vol. 5: Iss. 6. <https://doi.org/10.4148/2378-5977.7800>

This report is brought to you for free and open access by New Prairie Press. It has been accepted for inclusion in Kansas Agricultural Experiment Station Research Reports by an authorized administrator of New Prairie Press. Copyright 2019 Kansas State University Agricultural Experiment Station and Cooperative Extension Service. Contents of this publication may be freely reproduced for educational purposes. All other rights reserved. Brand names appearing in this publication are for product identification purposes only. No endorsement is intended, nor is criticism implied of similar products not mentioned. K-State Research and Extension is an equal opportunity provider and employer.



---

# Crop Yield and Yield Stability as Affected by Long-Term Tillage and Nitrogen Fertilizer Rates in Dryland Wheat and Sorghum Production Systems

## Abstract

A major challenge for agronomists is developing cropping systems that exhibit superior performance across variable environmental conditions, especially precipitation. Long-term field research trials provide a direct measure of the effect of environmental conditions within the context of treatment effects. Here we investigated the impact of tillage practices and nitrogen (N) rates on yields for dryland wheat and sorghum as influenced by weather and precipitation. The study focused on a long-term (40 years) tillage and N fertilizer experiment established in 1975 and managed as a split-split-plot arrangement of rotation (winter wheat-grain sorghum-fallow) with three tillage systems (conventional tillage (CT), reduced tillage (RT), and no-tillage (NT)), and four N application rates (0, 20, 40, and 60 lb N/a) in a randomized complete block design. Results were analyzed using analysis of variance and stability analysis. Yields of winter wheat and grain sorghum significantly decreased with decreases in both tillage intensity and N fertilizer rates. The mean yield for winter wheat was significantly correlated with total precipitation but was not correlated with precipitation during fallow periods or during the growing season. Wheat yield and total precipitation were correlated for the highest N fertilizer rates across all tillage treatments, but not for low N fertilizer rates. Grain sorghum yield was correlated with precipitation during the growing season, particularly for the highest N fertilizer rates. The stability analysis showed grain yield with each tillage practice was more stable with increasing N fertilizer rates.

## Keywords

conventional tillage, reduced tillage, no tillage, N fertilizer, yield stability, precipitation correlation, dryland systems

## Creative Commons License



This work is licensed under a [Creative Commons Attribution 4.0 License](https://creativecommons.org/licenses/by/4.0/).

# Crop Yield and Yield Stability as Affected by Long-Term Tillage and Nitrogen Fertilizer Rates in Dryland Wheat and Sorghum Production Systems

*M. Majrashi, A.K. Obour, and C.J. Moorberg*

## Summary

A major challenge for agronomists is developing cropping systems that exhibit superior performance across variable environmental conditions, especially precipitation. Long-term field research trials provide a direct measure of the effect of environmental conditions within the context of treatment effects. Here we investigated the impact of tillage practices and nitrogen (N) rates on yields for dryland wheat and sorghum as influenced by weather and precipitation. The study focused on a long-term (40 years) tillage and N fertilizer experiment established in 1975 and managed as a split-split-plot arrangement of rotation (winter wheat-grain sorghum-fallow) with three tillage systems (conventional tillage (CT), reduced tillage (RT), and no-tillage (NT)), and four N application rates (0, 20, 40, and 60 lb N/a) in a randomized complete block design. Results were analyzed using analysis of variance and stability analysis. Yields of winter wheat and grain sorghum significantly decreased with decreases in both tillage intensity and N fertilizer rates. The mean yield for winter wheat was significantly correlated with total precipitation but was not correlated with precipitation during fallow periods or during the growing season. Wheat yield and total precipitation were correlated for the highest N fertilizer rates across all tillage treatments, but not for low N fertilizer rates. Grain sorghum yield was correlated with precipitation during the growing season, particularly for the highest N fertilizer rates. The stability analysis showed grain yield with each tillage practice was more stable with increasing N fertilizer rates.

## Introduction

The United States Great Plains region is critically important in the production of winter wheat and grain sorghum. Agricultural production in western Kansas, like most of the Great Plains, is primarily limited by water (Obour et al., 2015). Water limitations are a concern in dryland cropping systems due to limited precipitation and greater climatic variability (Guo et al., 2012). Developing crop production systems that increase water storage in dryland is of utmost importance. Soil water storage plays a crucial role in stabilizing and increasing crop yields (Unger et al., 1997), and conservation tillage is a highly effective mechanism to conserve soil water because of the surface residue cover (Unger et al., 1997). No-tillage or RT have led to reduced erosion,

increased soil organic matter, and increased precipitation storage in the Great Plains (Logan et al., 1991; Thomas et al., 2007; Triplett and Dick, 2008).

Nitrogen is the most limiting nutrient for crops and is a key component to increasing crop yield. The soil N cycle is regulated by soil microbes, which facilitate conversion of organic N into readily available plant minerals, such as nitrate and ammonium, through the process of mineralization (Fageria et al., 1991; Montemurro, 2009). The mineralization process is influenced by the crop production system, tillage, and N fertilizer application method.

Agricultural research is usually based on short-term studies, but sustainable agriculture requires long-term field and laboratory experiments capable of determining the complex soil-plant-climate management interactions. A stable agronomic system is one in which changes in response to environmental conditions are minimized (Lightfoot et al., 1987). Long-term field experiments play an essential role in understanding the complex plant-soil-climate interactions and their effect on crop yield (Army and Kemper, 1991). It's important to assess interaction effects from year-to-year and within treatments in long-term fertility experiments. However, interpretation of interaction effects using conventional analysis methods (e.g. analysis of variance) is difficult because of the complexity of environmental factors. Stability analysis can be useful for continuous-site experiments where treatments are applied to the same plot over a period of time. Stability analysis allows performance of management practices to be evaluated with respect to environmental factors that change over time within a given location.

Previous research on yield stability analysis has focused primarily on crop genotypes across environments and their interaction (Yate and Cochran, 1938; Finlay and Wilkinson, 1963; Eberhart and Russel, 1966; and Crossa, 1988). However, stability analysis is becoming more commonly used in long-term fertility experiments. Raun et al., (1993) conducted two long-term experiments on wheat (*Triticum aestivum*) and corn (*Zea mays L.*) fertility trials. They used stability analyses to determine that wheat responded poorly to beef manure (302 lb N/a) as an N source compared to a chemical fertilizer treatment. They also used stability analysis in an irrigated corn experiment and determined that sidedressing with anhydrous ammonia resulted in higher yield compared to sidedressing or preplanting with urea-ammonium nitrate (Raun et al., 1993). Daigh et al. (2018), examined long-term tillage management and crop rotations in multiple locations in the Midwest. Using stability analysis, they concluded there is no significant difference in yield between chisel-plow (CP) and NT managed corn/soybean. Further, yield stability analysis of environmental conditions showed no differences between NT and CP yield stabilities among years (Daigh et al., 2018). In a 24-year study, Nielson and Vigil (2018) reported that wheat yield stability was more stable for NT wheat-fallow when compared to CT wheat-fallow, and both NT wheat-fallow and CT wheat-fallow were more stable than more intensive crop rotations.

There is limited information on yield stability under long-term tillage practices and N application rates for wheat-grain sorghum-fallow rotations in dryland production systems in the Great Plains. The present study utilized a long-term field experiment initiated in 1975 to evaluate the effects of tillage and N fertilizer application rates on wheat and grain sorghum yield and yield stability. We hypothesize that increasing N

application rates and reducing tillage intensity would increase grain yield and yield stability. The objectives of this study were to evaluate long-term effects of tillage practices and N application rates on grain yield and yield stability of winter wheat and grain sorghum, and to evaluate mean yield correlation with precipitation timing in a dryland winter wheat-grain sorghum-fallow rotation system.

## 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; U.S. Department of Agriculture 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 measuring 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 establishment in 1965.

The data on grain yield for winter wheat and sorghum have been recorded from 1975 to 2003 for wheat and 1975 to 2002 for sorghum, and from 2013 to 2018 for both crops. There were no yield data for wheat or sorghum from 2003 to 2012 or 2002 to 2012 due to changes in research personnel; however, the plots and treatment were maintained throughout the study period. Precipitation data over the study period were documented using the Weather Data Library of Kansas Mesonet station at Hays, which is located 1.5 miles from the study site. Grain yield of both crops was determined by harvesting 5 ft × 100 ft area from the middle portion of each plot using a small combine harvester. Grain moisture content at harvest was determined using a DICKEY-john grain moisture tester (DICKEY-john Inc., Auburn, IL) and data were adjusted to 13.5% moisture content. The precipitation amounts during fallow ( $P_{\text{fallow}}$ ), crop growing season ( $P_{\text{growing}}$ ), and total amounts over the entire cycle ( $P_{\text{total}}$ ), i.e. the sum of precipitation during the growing season and preceding fallow period, for each crop were calculated for each year of the study. For winter wheat, the fallow period started at the time of sorghum harvest in October and ended at wheat planting in October of the following year, and the growing season spanned the time from wheat planting in October until wheat harvest the following June. For grain sorghum the fallow period begins at wheat harvest in July and goes until sorghum planting in June of the following year, and the sorghum growing season spanned the time from planting in June until sorghum harvest in October that same year.

Data for winter wheat and grain sorghum yield in all years throughout 1975 to 2014 (data are missing from 2004 for wheat, and from 2003–2012 for sorghum) were analyzed for variance (ANOVA) using PROC MIXED procedure in SAS (v. 9.4, SAS Inst., Cary, NC) and the Tukey's Honest Significant Difference was used for mean comparisons with an alpha ( $\alpha$ ) of 0.05.

The yield stability analysis was performed using linear regression analysis as described by Raun et al., (1993). For the aim of this study, the stability was adapted to investigate and compare yield stability of winter wheat and grain sorghum under three tillage practices (CT, RT, and NT) within four N application rates (0, 20, 40, and 60 lb N/a) for 30 years as the environment mean yield (as the average yield of all treatments in a given year).

## Results

### *Precipitation Throughout Study Period*

The precipitation amounts during fallow ( $P_{\text{fallow}}$ ), growing season ( $P_{\text{growing}}$ ), and total ( $P_{\text{total}}$ ) for winter wheat and grain sorghum are presented in Figure 1A and Figure 1B, respectively. These figures illustrate the year-to-year variation in precipitation. The  $P_{\text{total}}$  for winter wheat growing seasons was highest in 1993, 1994, and 2007 with more than 45 inches. A significant amount of this precipitation came during the fallow period in those years. The highest amount of  $P_{\text{total}}$  (more than 50 inches) occurred in 1990, and 2013 had less than 24 inches (Figure 1A). The highest total precipitation for grain sorghum for the growing season occurred during 1993 and the least amount of precipitation (22 inches), for the growing season occurred in 1983 (Figure 1B).

### *Yield Response*

Winter wheat grain yield was significantly affected by year, tillage, N rate, and their interactions (Table 1). Tillage  $\times$  year, and tillage  $\times$  N rate  $\times$  year interaction effects on grain sorghum yields were not significant. However, N rate and tillage had effect on sorghum yields (Table 1). The greatest winter wheat yield occurred in 1987; the lowest average yield occurred in 1989 and 2014 (Figure 2A). The highest and lowest average yields for grain sorghum occurred in 1986 and 1983, respectively (Figure 2B). Winter wheat and grain sorghum yields with less intensive tillage and reduced N rates were smaller than those obtained with CT (Table 2). In general, the average yield of both winter wheat and grain sorghum decreased by reducing the intensity of tillage practices and increased by increasing N fertilizer application rate. The average yields of winter wheat and grain sorghum were highest with CT and an N application rate of 60 lb N/a.

The correlation analysis between precipitation and treatment responses are presented in Table 2. For winter wheat, the correlations between winter wheat grain yield and  $P_{\text{fallow}}$  and  $P_{\text{growing}}$  were not significant, but grain yield was significantly correlated to  $P_{\text{total}}$ . No statistically significant difference was found for the PF, for grain sorghum growing season. However, all the 11 mean yield treatment groups were correlated significantly with the GP for the growing season of sorghum grain. Among the treatment groups, only 4 of them (CT, NR 60 lb/a, CT N40, and N60 lb/a) had significant differences in mean yield of grain sorghum with  $P_{\text{total}}$ . The time trend or a pattern was correlated with winter wheat in relation to the  $P_{\text{total}}$  for the growing season. Whereas for the mean

yield of grain sorghum, the trend was correlated to the precipitation during  $P_{\text{growing}}$  the given time period only. Individually, reduced tillage and N rate of 40 lb N/a had the highest correlations with winter wheat yield only for the full growing season. Logically, the interaction of those treatments also had the highest correlation with winter wheat yield during that time frame. For grain sorghum, NT during the growing season had the highest correlation for tillage treatments. Applying N at 60 lb/a had the highest correlation with grain sorghum yield. Overall, the highest correlation with grain sorghum yield occurred with the interaction of the CT and N rate of 60 lb/a. Correspondingly, a correlation exists between the mean tillage practices (CT, RT, and NT) and the sum of the  $P_{\text{total}}$  in relation to the two highest N rates (40 and 60 lb N/a).

### *Stability Analysis*

The stability analysis provided a valid means of assessing this data set, while also allowing visual observation of treatment interactions with the environment mean (Figure 5 and Table 3). A model was built using linear regression with tillage practices nested within N fertilization rates. These equations significantly corresponded to the environmental mean. Overall, the regression analysis indicates that the R-square of all of the equations were statistically significant at the 5% level. The regression equation with the best fit, highest R-square, for winter wheat was RT with 40 lb N/a. The best fit for grain sorghum was CT with 20 lb N/a. For winter wheat, there was a clear trend in the intercept and slope across all treatments. As the N application rate increased, the intercept decreased and slope increased. This trend held for all tillage treatments. However, the equations for grain sorghum did not show a clear trend in the intercept and slope components as related to the treatments. At the same time, though, the R-squares of all the grain sorghum regression equations were high and statistically significant. The stability analysis for treatments regressed on the environment mean for both winter wheat and grain sorghum demonstrates an advantage of higher N rates with intensive tillage practices.

### **References**

- Army, T. J., and Kemper, D. (1991). Support for long-term agricultural research. *Agronomy Journal*, 83(1), 62-65.
- Crossa, J. (1988). A comparison of results obtained with two methods for assessing yield stability. *Theoretical and applied genetics*, 75(3), 460-467.
- Daigh, A. L., Dick, W. A., Helmers, M. J., Lal, R., Lauer, J. G., Nafziger, E., and Cruse, R. (2018). Yields and yield stability of no-till and chisel-plow fields in the Midwestern US Corn Belt. *Field Crops Research*, 218, 243-253.
- Eberhart, S. A., and Russell, W. A. (1966). Stability parameters for comparing varieties 1. *Crop Science*, 6(1), 36-40.
- Fageria, N. K., Baligar, V. C., and Jones, C. A. (1991). Growth and mineral nutrition of field crops. Marcel and Dekker.
- Finlay, K. W., and Wilkinson, G. N. (1963). The analysis of adaptation in a plant-breeding programme. *Australian journal of agricultural research*, 14(6), 742-754.

- Guo, S., Zhu, H., Dang, T., Wu, J., Liu, W., Hao, M., and Syers, J. K. (2012). Winter wheat grain yield associated with precipitation distribution under long-term nitrogen fertilization in the semiarid Loess Plateau in China. *Geoderma*, 189, 442–450.
- Lightfoot, C. W. F., Dear, K. B. G., and Mead, R. (1987). Intercropping sorghum with cowpea in dryland farming systems in Botswana. II. Comparative stability of alternative cropping systems. *Experimental agriculture*, 23(4), 435-442.
- Logan, T. J., Lal, R., and Dick, W. A. (1991). Tillage systems and soil properties in North America. *Soil and Tillage Research*, 20(2–4), 241–270.
- Montemurro, F. (2009). Different nitrogen fertilization sources, soil tillage, and crop rotations in winter wheat: effect on yield, quality, and nitrogen utilization. *Journal of Plant Nutrition*, 32(1), 1–18.
- Nielsen, D. C., and Vigil, M. F. (2018). Wheat yield and yield stability of eight dryland crop rotations. *Agronomy Journal*, 110(2), 594-601.
- Obour, A. K., Stahlman, P. W., and Thompson, C. A. (2015). Wheat and Grain Sorghum Yields as Influenced by Long-term Tillage and Nitrogen Fertilizer Application. *Int. J. Soil Plant Sci.*, 7, 19–28.
- Raun, W. R., and Barreto, H. J. (1993). Use of stability analysis for long-term soil fertility experiments. *Agronomy Journal*, 85(1), 159–167.
- Thomas, G. A., Dalal, R. C., and Standley, J. (2007). No-till effects on organic matter, pH, cation exchange capacity and nutrient distribution in a Luvisol in the semi-arid subtropics. *Soil and Tillage Research*, 94(2), 295–304.
- Triplett, G. B., and Dick, W. A. (2008). No-tillage crop production: A revolution in agriculture!. *Agronomy journal*, 100(Supplement\_3), S-153.
- Unger, P. W., Schomberg, H. H., Dao, T. H., and Jones, O. R. (1997). Main content area Tillage and crop residue management practices for sustainable dryland farming systems. *Annals of Arid Zone*, 36(3), 209–232.
- Yates, F., and Cochran, W. G. (1938). The analysis of groups of experiments. *The Journal of Agricultural Science*, 28(4), 556-580.



**Table 1. The analysis of variance for winter wheat yield and grain sorghum of 404 plots in Hays, KS, with three different constant tillage practices (conventional tillage, reduced tillage, and no-tillage) nested with four nitrogen (N) fertilizer rates (0, 20, 40, and 60 lb N/a)**

Treatment effect	Yield of winter wheat			Yield of grain sorghum		
	DF <sup>†</sup>	F Value	Pr > F	DF	F Value	Pr > F
Year	30	447.56	<0.0001	29	155.52	0.0021
Tillage	2	203.37	<0.0001	2	8.31	<0.0001
Year × tillage	60	16.03	<0.0001	58	3.61	0.0842
N rate	3	1818.24	<0.0001	3	134.90	<0.0001
Year × N rate	90	18.50	<0.0001	87	2.94	<0.0001
Tillage × N rate	6	9.29	<0.0001	6	0.81	<0.0001
Year × tillage × N rate	180	1.45	0.0063	174	0.58	0.7621

<sup>†</sup>DF indicates degrees of freedom.

\*F value is an output from the statistical model.

§Pr > F is the probability of a greater F value, and indicates a p-value for the effect of model on responses at the level of significance.

Tests were performed with an  $\alpha$  of 0.05.

**Table 2. The average yield of winter wheat and grain sorghum and their Pearson Correlation Coefficients with precipitation before, during, and total growing season in 404 plots in Hays, KS, with three different constant tillage practices (CT, RT, and NT) nested with four nitrogen (N) fertilizer rates (NR) (0, 20, 40, and 60 lb N/a)**

Year	Mean yield of winter wheat				Mean yield of grain sorghum			
	lb/a†	Correlation (r) ‡			lb/a†	Correlation (r) ‡		
		P <sub>fallow</sub> §	P <sub>growing</sub> §	P <sub>total</sub> §		P <sub>fallow</sub> §	P <sub>growing</sub> §	P <sub>total</sub> §
2050		0.18	0.22	0.36*	3786	0.02	0.37*	0.29
Tillage systems								
CT	2135a	0.20	0.19	0.35*	3811a	0.10	0.39*	0.37*
RT	2091b	0.17	0.28	0.38*	3825a	-0.004	0.28	0.21
NT	1925c	0.15	0.17	0.29	3721b	-0.03	0.41*	0.29
Nitrogen rates (NR)								
NR0	1530d	0.04	0.20	0.20	3136d	-0.05	0.32	0.21
NR20	2006c	0.12	0.21	0.29	3714c	0.02	0.35	0.28
NR40	2266b	0.24	0.22	0.42*	4064b	0.02	0.36*	0.29
NR60	2397a	0.23	0.22	0.41*	4228a	0.07	0.41*	0.36*
Interaction of tillage × N rate								
CT N0	1621g	0.09	0.21	0.25	3217e	0.04	0.31	0.26
CT N20	2099de	0.17	0.17	0.31	3791d	0.07	0.39*	0.34
CT N40	2340bc	0.24	0.18	0.40*	4024bc	0.13	0.35	0.36*
CT N60	2436a	0.24	0.19	0.38*	4206abc	0.14	0.45*	0.43*
RT N0	1585g	0.07	0.25	0.26	3157e	-0.08	0.22	0.11
RT N20	2054e	0.09	0.27	0.30	3729d	-0.01	0.26	0.19
RT N40	2300c	0.21	0.26	0.42*	4162abc	-0.01	0.28	0.20
RT N60	2393ab	0.20	0.26	0.41*	4250a	0.07	0.33	0.30
NT N0	1345h	0.004	0.11	0.09	3030e	-0.09	0.38*	0.23
NT N20	1832f	0.09	0.19	0.24	3623d	-0.008	0.38*	0.28
NT N40	2139d	0.20	0.19	0.35*	4009c	-0.05	0.42*	0.28
NT N60	2337bc	0.22	0.21	0.39*	4228ab	0.008	0.42*	0.32

†Significant differences in yield within each factor or interaction are indicated by letters a-f, where any yields with different letters are significantly different at the  $P < 0.05$  level.

‡Significant correlations at the  $P < 0.05$  level are indicated by \*.

§Precipitation during fallow ( $P_{\text{fallow}}$ ), growing season ( $P_{\text{growing}}$ ), and total precipitation ( $P_{\text{total}}$ ).

**Table 3. Linear regression analysis of grain yield stability of winter wheat and sorghum on environment mean in 404 plots in Hays, KS, with three different constant tillage practices (CT, RT, and NT) nested with four nitrogen rates (NR) (0, 20, 40, and 60 lb N/a)**

Treatment	Intercept	Std. error†	Slope	Std. error†	Red. DF‡	C.V.§	R <sup>2</sup> *
Winter wheat							
CT N0	91	211	0.75	0.0893	29	16	0.86
CT N20	-98	154	1.07	0.0653	29	9	0.90
CT N40	-158	133	1.22	0.0562	29	7	0.94
CT N60	-155	158	1.26	0.0671	29	8	0.92
RT N0	-41	208	0.80	0.0882	29	16	0.74
RT N20	-70	119	1.04	0.0505	29	7	0.94
RT N40	-127	115	1.18	0.0485	29	6	0.95
RT N60	-230	193	1.27	0.0820	29	10	0.89
NT N0	250	227	0.55	0.0964	29	21	0.53
NT N20	253	155	0.79	0.0657	29	11	0.83
NT N40	217	203	0.95	0.0859	29	12	0.81
NT N60	69	213	1.12	0.0903	29	11	0.84
Grain sorghum							
CT N0	129	277	0.82	0.0621	28	13	0.86
CT N20	89	161	0.98	0.0362	28	7	0.96
CT N40	44	219	1.05	0.0490	28	8	0.94
CT N60	368	279	1.03	0.0625	28	10	0.91
RT N0	417	309	0.74	0.0692	28	15	0.80
RT N20	49	224	0.97	0.0503	28	9	0.93
RT N40	-128	209	1.13	0.0468	28	8	0.95
RT N60	164	200	1.08	0.0450	28	7	0.95
NT N0	-194	347	0.85	0.0778	28	17	0.81
NT N20	-344	263	1.04	0.0590	28	11	0.92
NT N40	-411	241	1.16	0.0541	28	9	0.94
NT N60	-183	317	1.16	0.0710	28	11	0.91

†Std. error indicates standard error.

‡Red. DF is residues of degree of freedom.

§C.V. is presented the coefficient of variability.

\*R<sup>2</sup> is the coefficient of determination and indicates a significant linear regression model of yield with environment mean at the with an  $\alpha$  of 0.05.

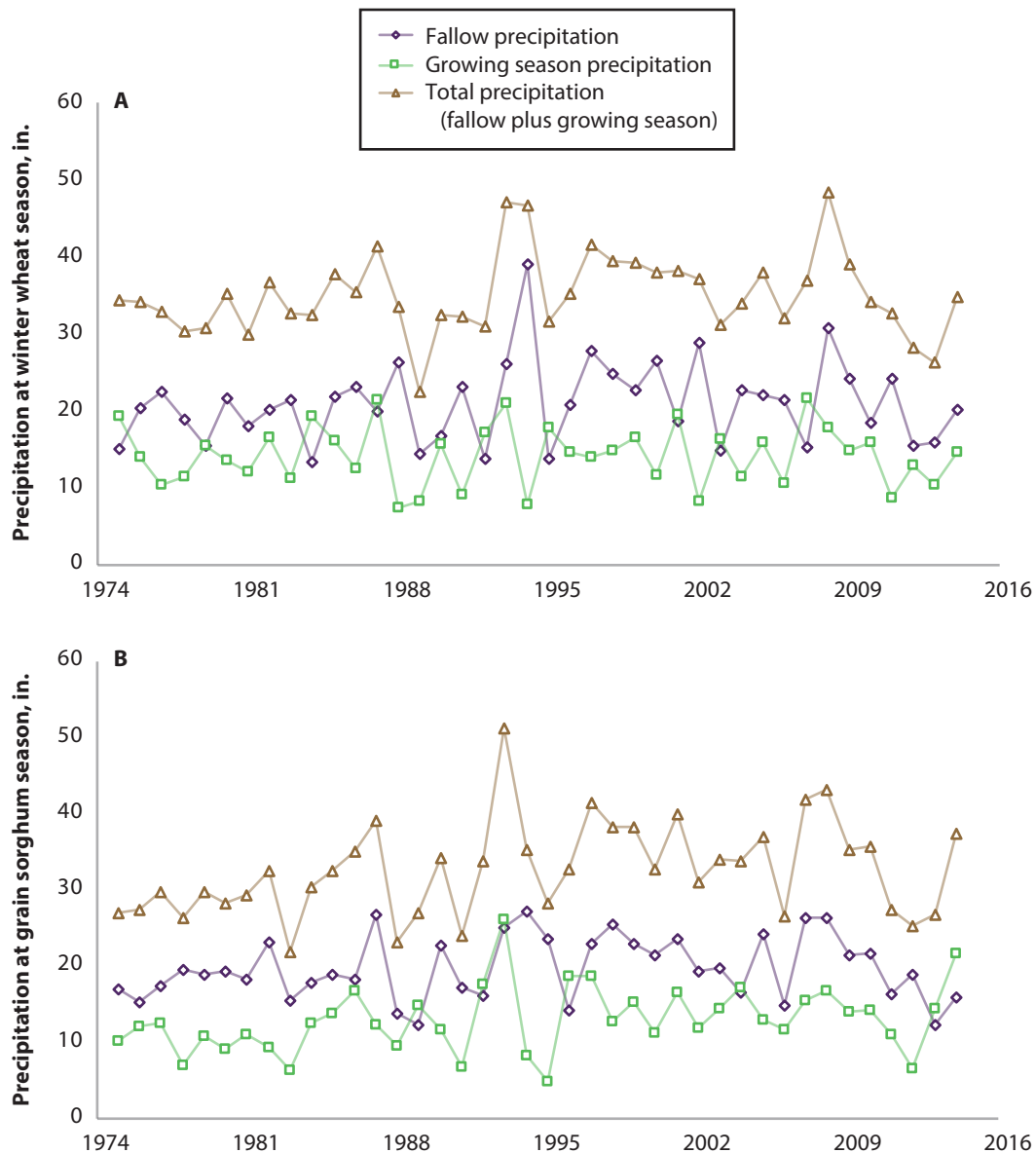


Figure 1. Precipitation during fallow period ( $P_{\text{fallow}}$ ), in the growing season ( $P_{\text{growing}}$ ), and fallow plus growing season ( $P_{\text{total}}$ ) of each given year for winter wheat (A) and grain sorghum (B) in Hays, KS.

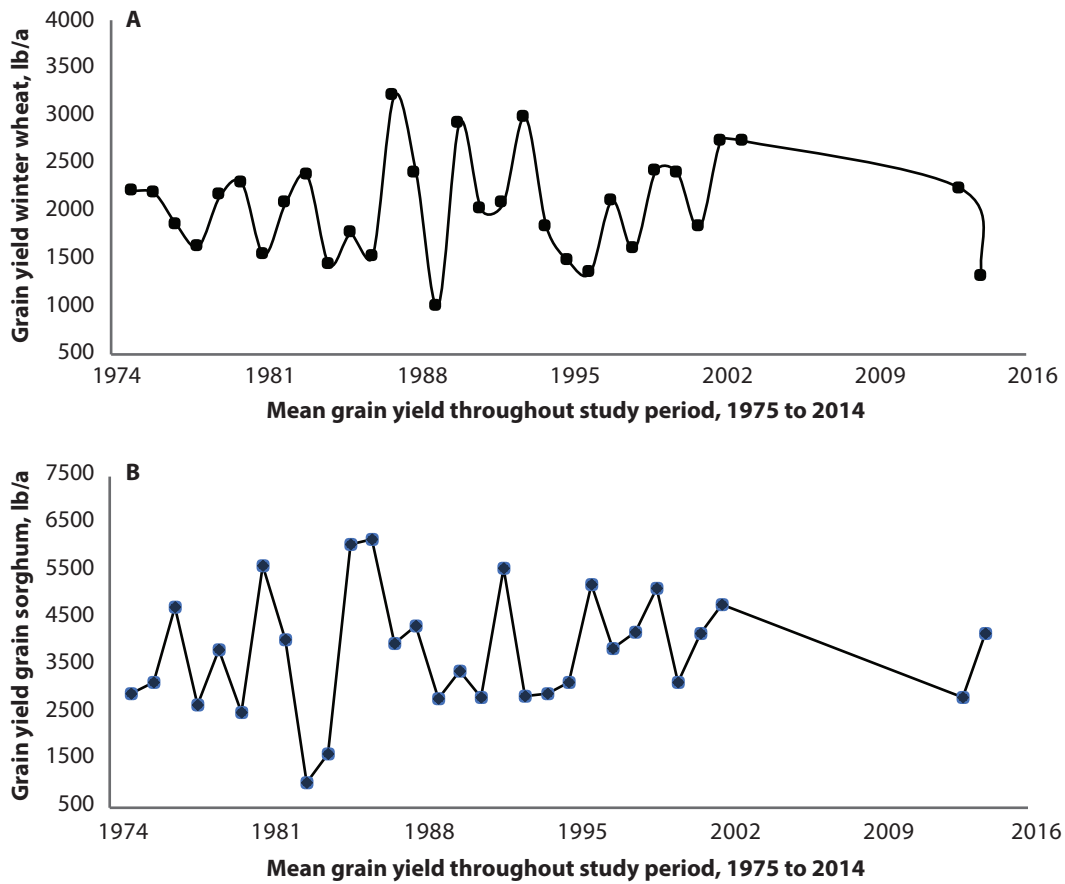


Figure 2. The trend of mean grain yield of winter wheat (A) and grain sorghum (B) across treatments throughout the study period, 1975 to 2014, as affected by years (data are missing from 2004 for wheat, and from 2003–2012 for sorghum).

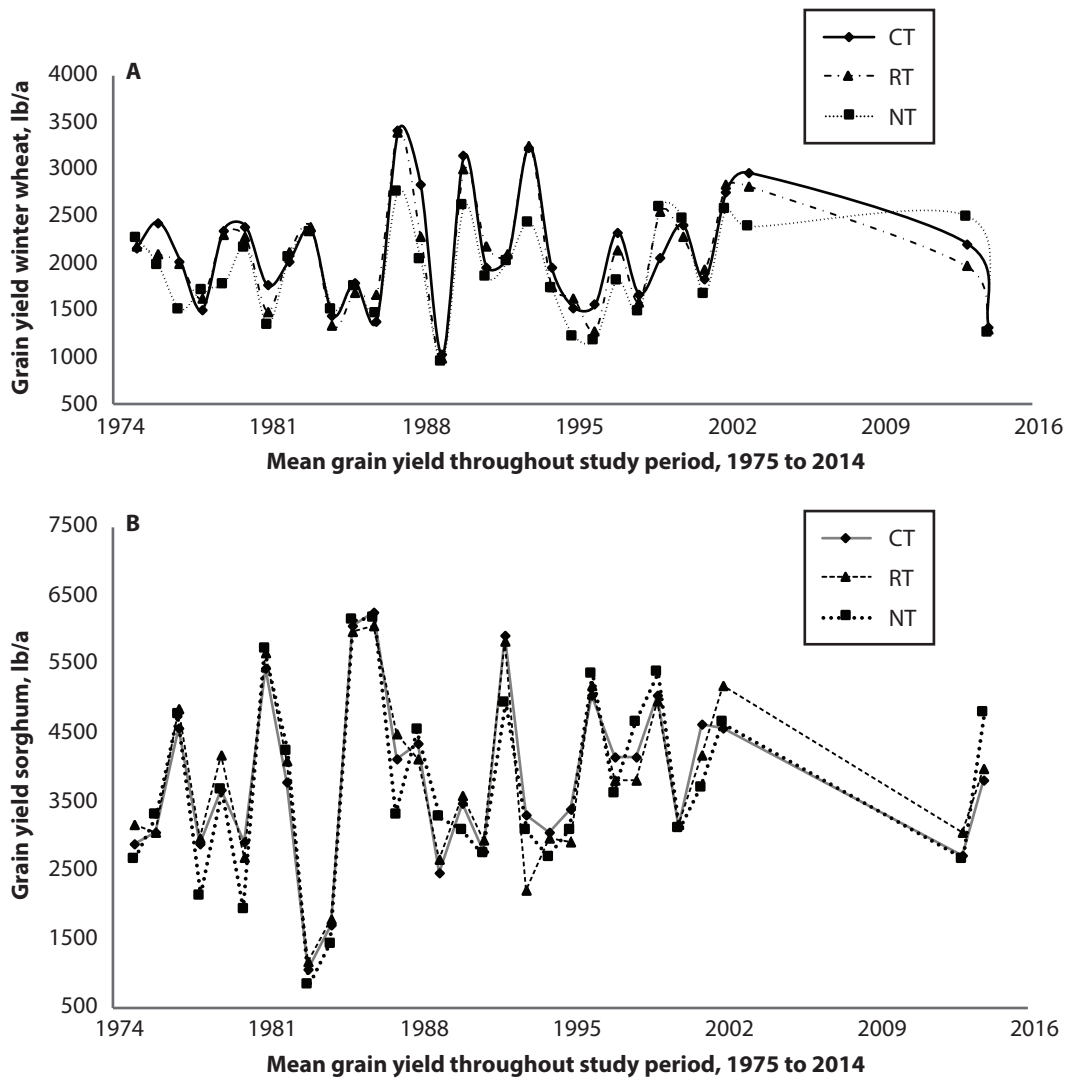


Figure 3. The trend of mean grain yield of winter wheat (A) and sorghum (B) across nitrogen fertilizer rates as affected by tillage practices (conventional tillage, CT; reduced tillage, RT; and no-tillage, NT), throughout the study period, 1975 to 2014.

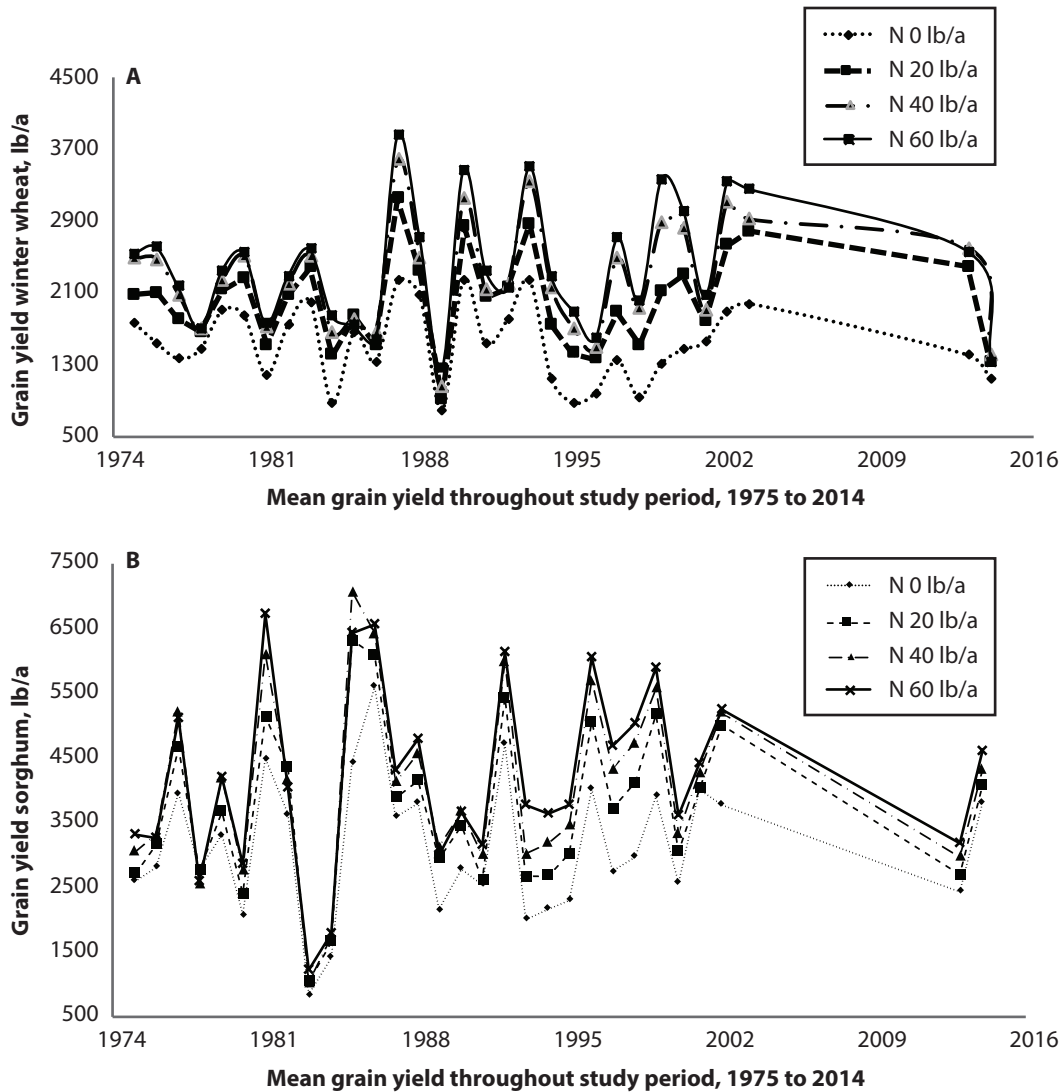


Figure 4. The trend of mean grain yield of winter wheat (A) and sorghum (B) across tillage practices as affected by nitrogen rates throughout the study period, 1975 to 2014.

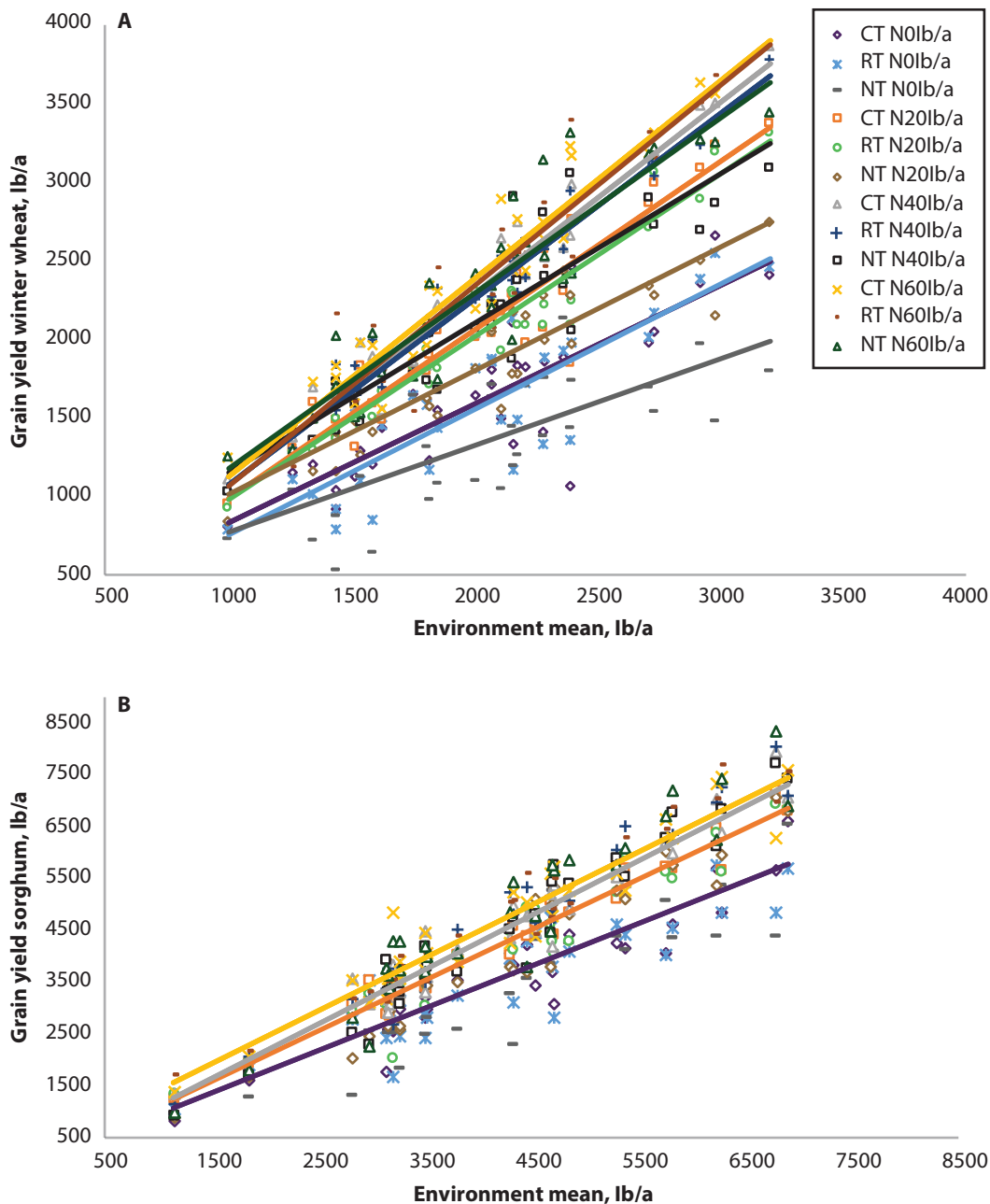


Figure 5. Linear regression of winter wheat (A) and sorghum grain (B) yield on the environment mean at affected by tillage and nitrogen (N) fertilizer rates in Hays, KS. Data are averaged from 1975 to 2014.