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Original Research Article
**Wheat and Grain Sorghum Yields as Influenced
by Long-Term Tillage and Nitrogen Fertilizer
Application**

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ABSTRACT

Tillage, choice of crops in a rotation, and fertilizer management affect crop yields. Limited information exist on long-term interaction effects of tillage and nitrogen (N) fertilizer management on grain yield and precipitation use efficiency (PUE) in intensified cereal-based cropping systems. A study was initiated at the Kansas State University Agricultural Research Center-Hays in 1975 to investigate the effect of tillage intensity [conventional tillage (CT), reduced tillage (RT) and No-till (NT)] and N fertilizer rates (0, 22, 45 and 67 kg N ha⁻¹) on wheat and grain sorghum yields. Grain yields and PUE for both wheat and grain sorghum were significantly ($P < 0.0001$) affected by year \times N application rate \times tillage interaction. Across all N rates and tillage practices, grain yields and PUE were greater in years of higher precipitation compared to years when precipitation amounts were below the long-term average. Wheat and sorghum yields for RT plots were equal or greater than CT in most years at each N rate. Grain yields and PUE in the NT plots were lower than CT and RT at lower N rates. However, at the highest N rate, grains yields were not different among the tillage systems. Regardless of tillage practice, grain yield increased with increasing N fertilizer application rate. Based on our findings, higher N application rates (> 67 kg N ha⁻¹) may be required to maximize both wheat and grain sorghum yields with any of the tillage systems.

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Keywords: Nitrogen fertilizer; Tillage; Precipitation use efficiency; Conventional tillage; No-tillage.

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1. INTRODUCTION

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Soil moisture availability and N management are some of the major limitations to crop production in dryland cropping systems in the central Great Plains. Crop yields in dryland cropping systems are directly related to available soil moisture at planting and in-season precipitation amounts received [1]. Due to water limitations, crop-fallow has been the traditional dryland cropping system in the Great Plains region [2]. However, the use of CT operations for weed control during the fallow period has resulted in insufficient crop residue return to the soil, depletion of soil organic matter (SOM), declining soil fertility, soil erosion and inefficient water storage [3-5].

32 In recent years, introduction and adoption of reduced tillage (RT) and no-till (NT) practices
33 have led to increased moisture storage and allowed crop intensification in most of the Great
34 Plains. Tillage and crop intensification will influence soil water availability, nutrient demand
35 and cycling within the soil profile due to different rooting patterns and nutrient requirements
36 of various crops involved in the rotation. Precipitation storage efficiency in a NT wheat-fallow
37 system was 35% compared to 20% in a CT wheat-fallow cropping system [6]. Economically,
38 intensive cropping combined with RT has been shown to be more profitable compared to
39 wheat-fallow systems in the Great Plains [7-8].

40 Nutrient requirements of intensified cropping systems are more complicated than a crop-
41 fallow system. For instance, significant $\text{NO}_3\text{-N}$ accumulates in the soil profile during the
42 fallow period in a crop-fallow system and may be available to the succeeding crop. In
43 contrast, the shortened fallow period due to continuous cropping may reduce N
44 mineralization and availability to crops in rotation [9]. In addition, high residue return to the
45 soil in intensified cropping systems can increase the risk of N loss through NH_3 volatilization.
46 Nitrogen immobilization by soil microbes when N is surface applied can also reduce N
47 availability to crops.

48 Nitrogen fertilizer is the most limiting nutrient to crop yields and the most expensive input
49 cost in crop production. Globally, nitrogen use efficiency (NUE) of cereal crop production is
50 about 33% [10]. Increasing N application rates results in a reduction in NUE in cereal crops.
51 For instance, NUE in a NT wheat-sorghum-fallow (W-S-F) cropping system varied from 86,
52 69, 56 and 45% for 28, 56, 84, and 112 kg N ha^{-1} , respectively [11]. Rising fertilizer costs,
53 low NUE and environmental concerns provide the impetus for developing N management
54 strategies that improve crop yields and reduce N losses to the environment. Because of the
55 high rainfall variability in the Great Plains, long-term field data is required to predict optimal N
56 rates for various crop production systems to avoid environmental risk associated with
57 excessive N application. Moreover, since the magnitude of crop yield response to applied N
58 fertilizer depends on available soil moisture, information on the long-term influence of tillage
59 and N fertility management on grain yield and PUE in the central Great Plains is needed to
60 document the performance of these intensive cropping systems. The objectives of this paper
61 are to i) determine long-term effects of tillage and N fertilizer application on grain yield, and
62 ii) investigate PUE after 29-yr of tillage and N fertilizer management in a wheat-sorghum-
63 fallow cropping system in west-central Kansas.

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65 **2. MATERIAL AND METHODS**

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68 **2.1 EXPERIMENTAL SET-UP**

69 This long-term experiment was initiated in the fall of 1965 on a Harney silt loam soil (fine,
70 montmorillonite, mesic Typic Agriustoll) at the Kansas State University Agricultural Research
71 Station in Hays (38°86' N, 99°27' W, and 609 m elevation) to evaluate the effect of tillage
72 intensity on crop yield under a W-S-F rotation. The three tillage practices were CT, RT, and
73 NT in a randomized complete block design with four replications. Each phase of the crop
74 rotation was present in each year of the study. The experiment was modified in 1975 to
75 include N application rates in a split-plot arrangement. The original tillage treatments (CT,
76 RT, and NT) were assigned to the main plots and the sub-plot factor was four N rates (0, 22,
77 45 and 67 kg N ha^{-1}). Plot sizes were 20.4 m × 30.5 m for the tillage plots, and 3.4 m × 30.5
78 m for the N application rate treatments. There was a 3.5 m wide border between tillage
79 treatments. Thompson and Whitney [12] describe further details on tillage operations and
80 weed management. Briefly, weed control and seedbed preparation were done with residue-
81 incorporating implements (disk, and mulch treader) in the CT plots, and residue-saving tools

82 (V-blade and sweeps) used in RT plots. Approximately 3 to 4 tillage operations were
83 performed from harvest to planting in the CT and RT plots. Only herbicides were used for
84 weed control in the NT plots. Appropriate herbicides were used to control weeds in wheat
85 and sorghum crops across tillage practices. Nitrogen was broadcasted as ammonium nitrate
86 in the fall prior to wheat planting. Nitrogen application for grain sorghum plots were also
87 done in the fall. Because soil test levels for available phosphorus and exchangeable
88 potassium were medium to high over the study period, N was the only fertilizer applied.
89 Wheat and sorghum cultivars varied over the study period. Grain yields were determined by
90 harvesting 1.5 m × 30.5 m area of each plot with a plot combine. Daily and yearly
91 precipitation data were recorded at the nearby weather station ~ 2.4 km from the study site.
92 Precipitation use efficiency for each tillage and N rate treatment was computed by dividing
93 grain yields (kg ha^{-1}) by annual precipitation (cm) as described by Varvel [13].

94 **2.2 Statistical Analysis**

95 Data for the 28-yr (grain sorghum) and 29-yr (wheat) were analyzed statistical for ANOVA
96 using the PROC MIXED procedure of SAS [14]. Tillage, N rate and year were considered as
97 fixed effects and replicates and their interactions were considered as random effects. The
98 LSMEANS procedure and associated PDIFF were used for mean comparisons. Interaction
99 and treatment effects were considered significant when *F* test *P* values were ≤ 0.05 . In
100 addition, regression analyses were conducted with the Proc Reg procedure in SAS to
101 determine the relationship between grain yield and N application rates.

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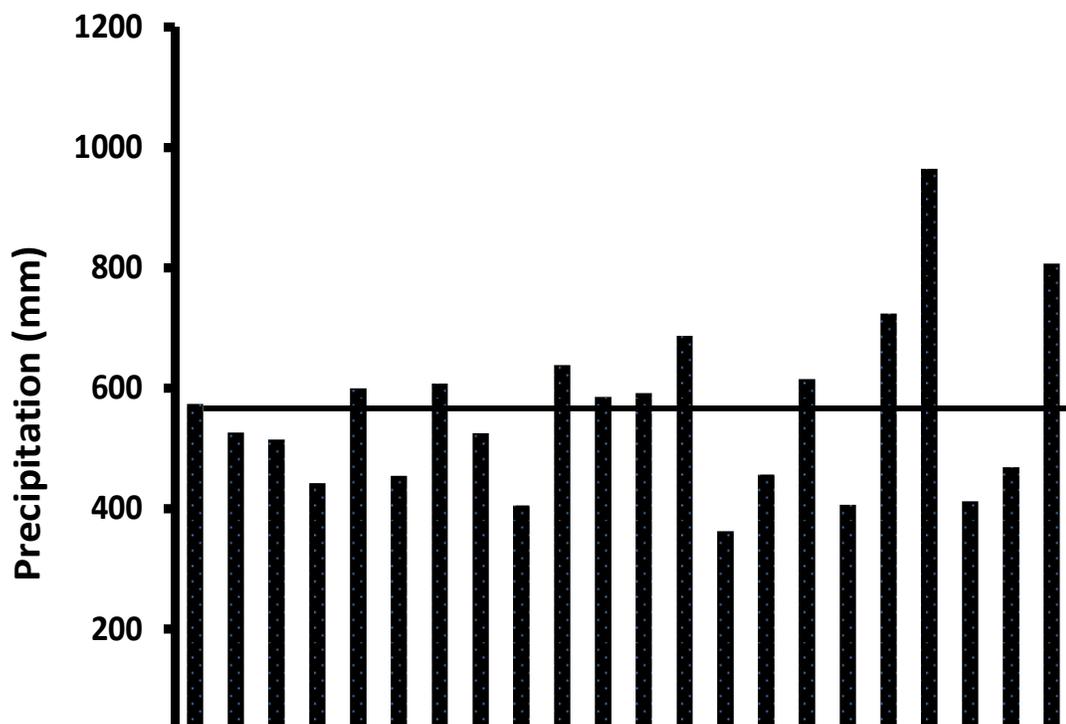
103 **3. RESULTS AND DISCUSSION**

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105 Annual precipitation amounts varied significantly over the study period (Fig.1). The long-term
106 (146-yr) average precipitation at the study site was 579 mm. In general, the 1993 and 1996
107 growing seasons recorded the highest precipitation amounts. The driest year was 1988, with
108 total annual precipitation of 363 mm (Fig. 1). In 15-yr of the 29-yr study, the amount of
109 precipitation received was equal or above the long-term average. In dryland situations, the
110 high variability in precipitation amounts received may cause crop yield variations.

111 Year × N application rate × tillage interaction significantly ($P < 0.0001$) affected wheat and
112 grain sorghum yields. The three-way interaction occurred due to the varied amounts of
113 precipitation received over the 29-yr study period. Across all N rates and tillage practices,
114 wheat grain yields were significantly greater in years of higher precipitation compared to
115 years when precipitation amounts were below the long-term average (Fig. 1 & 2). This
116 observation was expected because crop yields in the semi-arid Great Plains are highly
117 dependent on available soil moisture [1]. Regardless of tillage practice, grain yield increased
118 significantly with increasing N fertilizer application rates. The magnitude of N response for
119 each tillage practice was particularly greater in wet years (Fig. 2).

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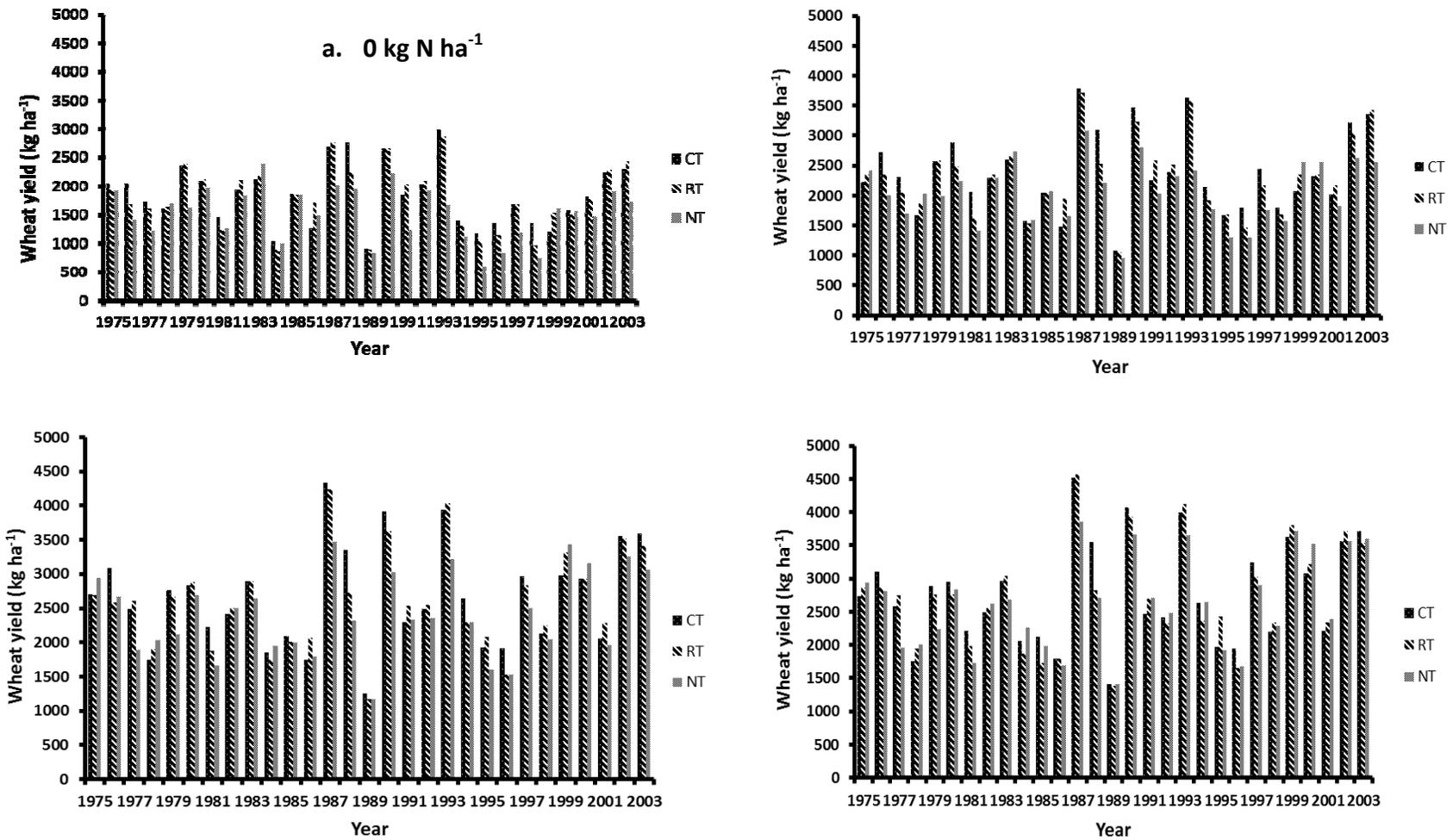


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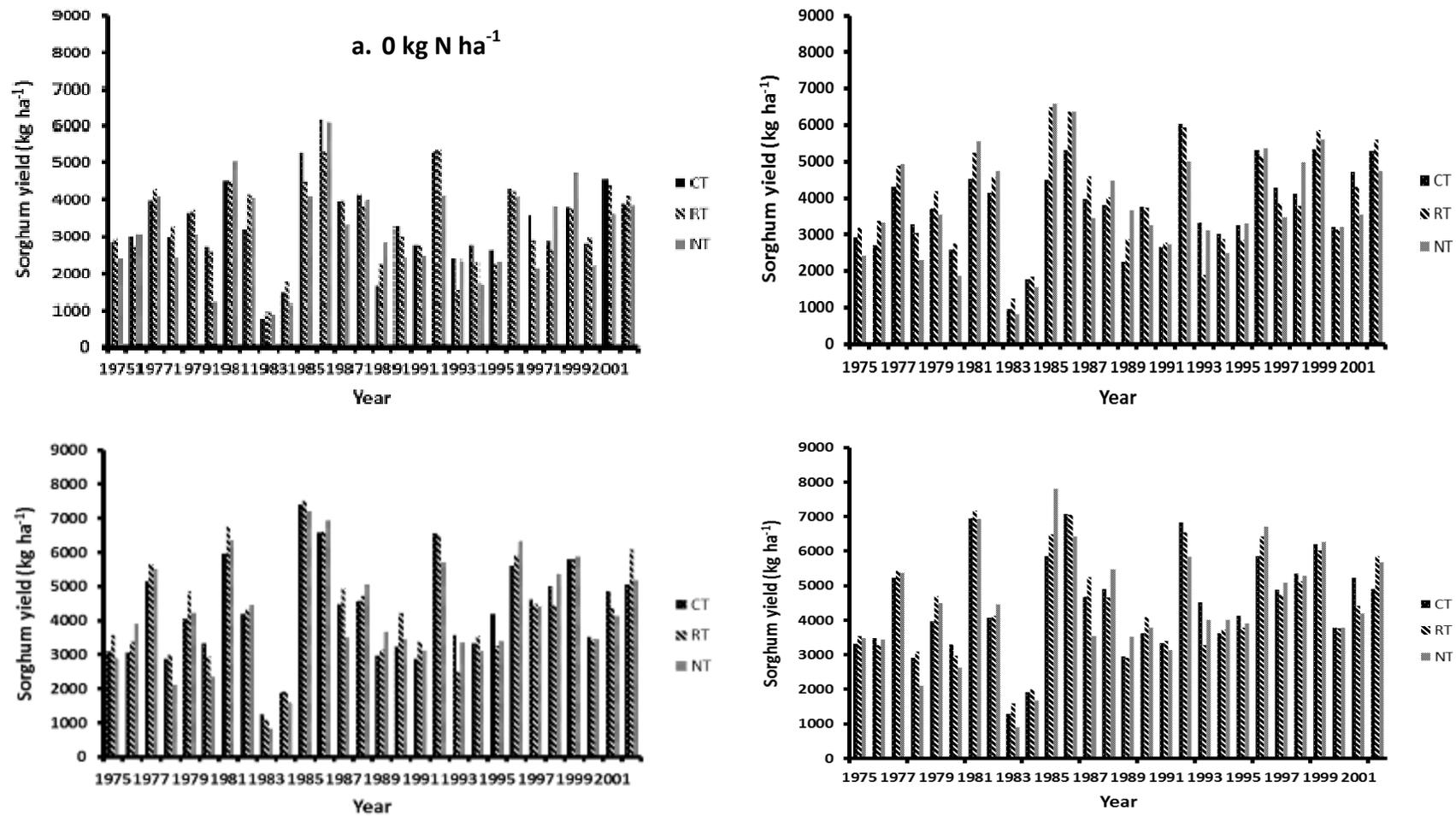
Fig. 1. Precipitation amounts received at Kansas State University Agricultural Research Center in Hays, KS from 1975 to 2003. Inserted line indicates 146-yr average annual precipitation (579 mm) at the study site.

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Wheat yields for RT plots were equal or greater than CT in most years at each N rate. Winter wheat yields under NT were significantly lower than CT and RT. The difference was more pronounced in wetter years and at lower N application rates (Fig. 2). These results agree with López-Bellido and López-Bellido [15] who reported greater wheat grain production in CT than NT systems. In a 12-yr study, Halvorson et al. [16] found spring wheat yields with RT were similar to CT in most years, but NT grain yields were lower than CT. Grain sorghum yields showed similar response as wheat. Though not consistent, NT yields were generally lower than CT and RT, especially at lower N application rates (Fig. 3). The lower wheat and sorghum grain yields with NT may be due to poor plant stands (caused by drier soil conditions at planting), increased weed competition due to poor weed control, and reduced N availability to wheat and sorghum crops caused by N immobilization from crop residue. The lack of adequate weed control in conservation tillage systems has been reported to reduce winter wheat yields compared to moldboard-plowed systems [17]. In our present study, poor control of invasive grass species tumblegrass [*Schedonnardus paniculatus* (Nutt.) Trel] and windmillgrass (*Chloris verticillata* Nutt.) in the NT plots compared to the CT and RT can cause significant yield reductions in the NT system. Since the significant year \times tillage \times N interactions were due to variation in precipitation amounts over the study period, we examined the influence of the main effects of tillage and N rate on crop yield and PUE.



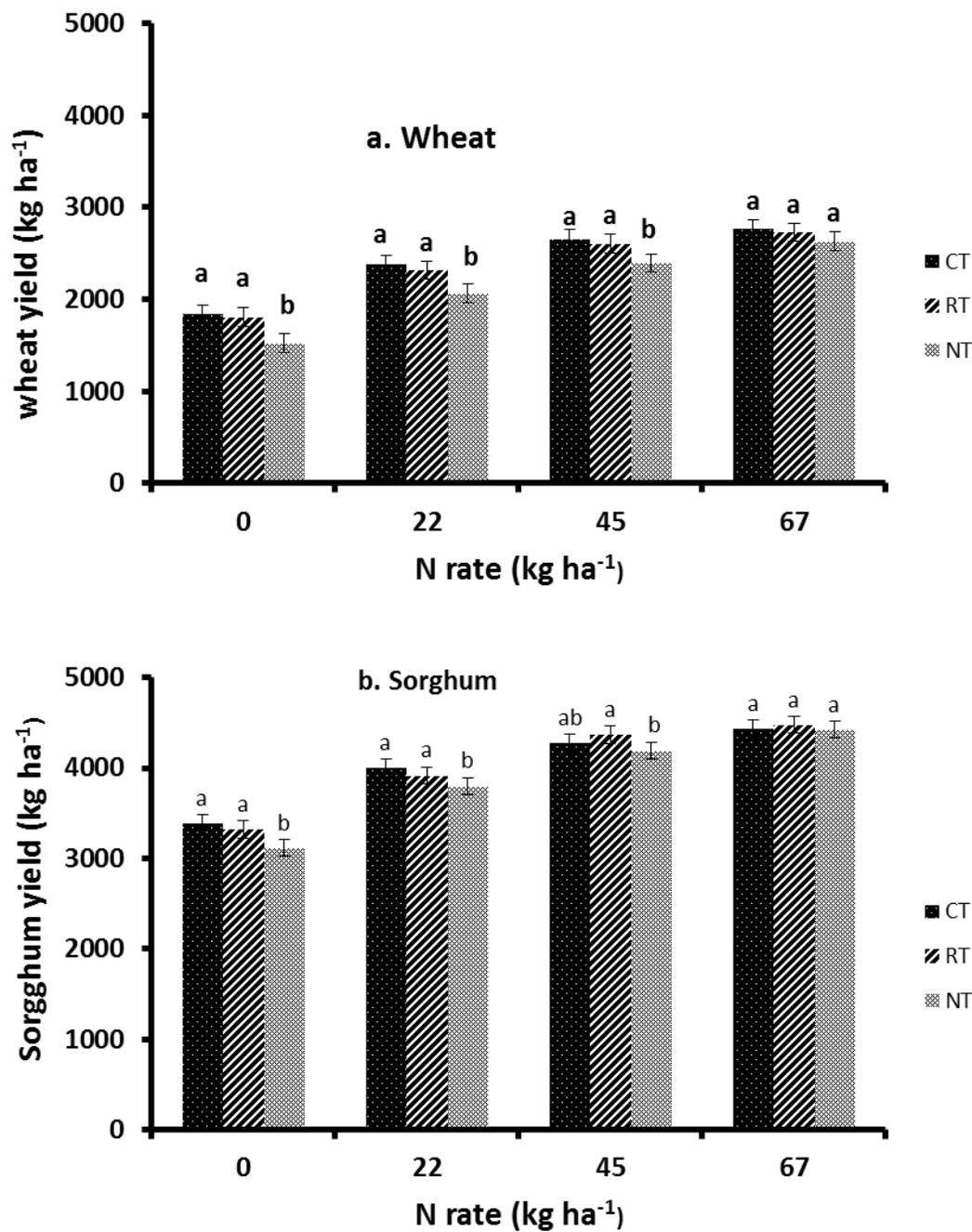
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 149 Fig. 2. Winter wheat grain yield as affected by tillage and nitrogen fertilizer application over 29-yr study period. Means are averaged over
 150 four replication (n = 4). CT, Conventional tillage; RT, Reduced tillage; NT, No-till.



151 Fig. 3. Sorghum grain yield as affected by tillage and nitrogen fertilizer application over 28-yr study period. Means are averaged over four
 152 replication (n = 4). CT, Conventional tillage; RT, Reduced tillage; NT, No-till.

153 The two- and three-way interaction with year does not convey any important agronomic information compared to the
154 impacts of N fertilizer application on grain yield stability in each of the tillage practices over the study period. Averaged
155 across years, grain yield for wheat and sorghum were significantly affected by tillage and N application (Fig. 4a). At lower
156 N rates, wheat grain yields were greater with CT and RT than with NT. However, at 67 kg N ha⁻¹, there were no yield
157 differences among tillage systems. Similarly, at 0 and 22 kg N ha⁻¹, grain sorghum yields with NT were lower than CT and
158 RT, but at 40 kg N ha⁻¹, grain yields were similar with NT and CT systems. At the highest N rate (67 kg N ha⁻¹); sorghum
159 yields were similar for all tillage systems (Fig. 4b). Locke and Hons [18] reported greater grain sorghum yields with CT
160 than NT at low N rates, but no yield differences between the two tillage practices at higher N rates. Similar responses
161 were found in barley. Grain yields of barley were found to be significantly lower under NT than CT when N rates were
162 between 0 to 33 kg N ha⁻¹, but at higher N rates (67 or 100 kg N ha⁻¹) NT produced equal or greater yields than CT [19].
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164 Reduced grain yields under NT at low N rates (0 to 45 kg ha⁻¹ in this study) may be due to immobilization of the applied N
165 by soil microorganisms. Increasing N application rate to 67 kg N ha⁻¹ may have reduced the effects of N immobilization by
166 providing adequate N for both crops. This implies additional N fertilizer application may be required to compensate for N
167 immobilization to avoid wheat and sorghum yield depressions when grown under NT systems.
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195 Fig. 4. Tillage and nitrogen application effects on (a) winter wheat and (b) sorghum grain yields over the study period.
 196 Data are averaged across years (29-yr for wheat and 28-yr for sorghum) and four replicates. Error bars represent one
 197 standard error of the mean. Means followed by the same letter (s) within N rate are not significantly ($P > 0.05$) different.
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200 Regression analysis showing winter wheat and sorghum yields as a function of N application rates over the study period
 201 in shown in Table 1. Regardless of tillage practice, grain yields increased with N fertilizer application but the amount of N
 202 required achieving maximum yields varied for the tillage systems. The N rate required to maximize wheat grain production
 203 was approximately 66, 70 and 87 kg N ha⁻¹ with CT, RT and NT, respectively. Grain sorghum yields with CT and RT
 204 systems were maximized at 68 kg N ha⁻¹ N, but 75 kg N ha⁻¹ was needed to maximize yields in NT (Table 1). Nitrogen
 205 application of 84 kg ha⁻¹ was identified as sufficient N amount to maximize wheat yields in NT wheat-corn-fallow and W-S-
 206 F cropping systems in Colorado [11, 20]. Based on the regression analysis, NT systems required 21 kg ha⁻¹ more N to
 207 maximize wheat yields compared to CT (Table 1). This finding agrees with those of Staggenborg et al. [21], who showed
 208 that winter wheat planted after grain sorghum required addition of 21 kg ha⁻¹ N to maximize grain yields compared to
 209 wheat following soybean. The authors attributed this to N immobilization from the higher sorghum residue. Though

210 ammonium nitrate was the N fertilizer source in our long-term study, potential N immobilization occurring in the NT plots
 211 can reduce N availability to wheat and grain sorghum thereby causing yield reductions.

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 213 Table 1. Regression equations for winter wheat and grain sorghum yields as a function of nitrogen application
 214 average of the study period.

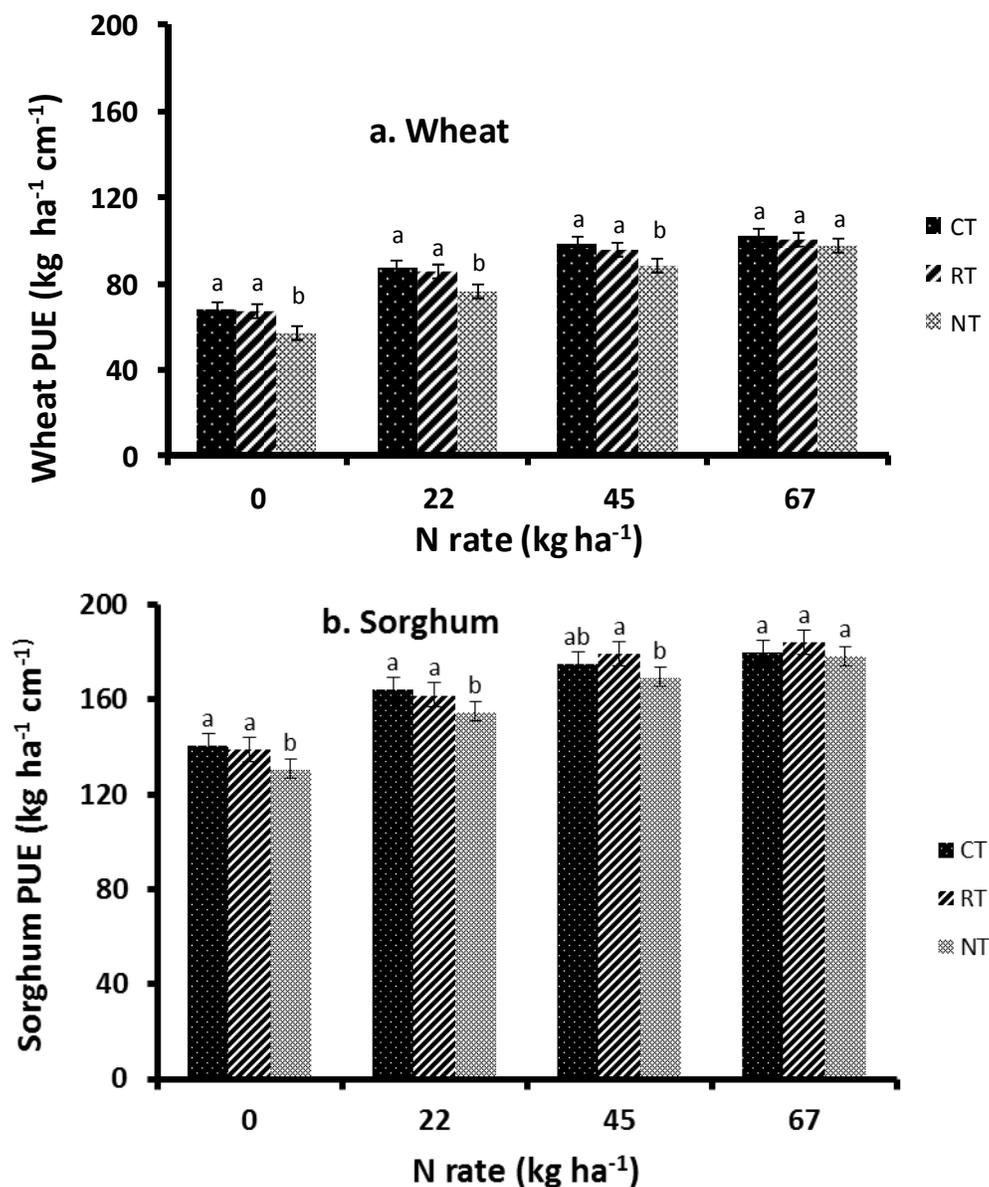
Tillage	†Equation: $y = a + bx + cx^2$				Maximum yield	N rate required to achieve maximum yield kg ha ⁻¹
	a	b	c	R ²		
Winter wheat						
Conventional tillage	1846.3	27.8	-0.21	0.99	2766	66.2
Reduced tillage	1810.4	26.7	-0.19	0.99	2748	70.3
No-tillage	1531.4	26.2	-0.15	0.99	2676	87.3
Grain Sorghum						
Conventional tillage	3405.0	30.1	-0.22	0.99	4435	68.4
Reduced tillage	3310.7	34.0	-0.25	0.99	4467	68.0
No-tillage	4466.7	34.4	-0.23	0.99	4412	74.8

215 † y = grain yield, kg ha⁻¹; x = N rate, kg ha⁻¹.

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 217 When averaged across tillage system, winter wheat grain production over the 29-yr growing seasons was 1725, 2253,
 218 2551, and 2710 kg ha⁻¹ for the 0, 22, 45 and 67 kg N ha⁻¹, respectively. Similarly, grain sorghum yields were 3278 kg ha⁻¹
 219 for the control (0 kg N ha⁻¹), 3907, 4280 and 4444 kg ha⁻¹ for the 22, 45, and 67 kg N ha⁻¹, respectively. The significantly
 220 higher yields of the 67 N ha⁻¹ rate compared to the lower N rates suggest the highest N rate used in this study was not
 221 adequate to optimize either wheat or grain sorghum yields.

222
 223 Precipitation use efficiency was significantly affected by year × N rate × tillage interaction. In addition, all main effects and
 224 their interaction were significant ($P < 0.0001$). The PUE for wheat and grain sorghum were greater in years with higher
 225 precipitation and greater grain yields. Increasing N rates resulted in significantly greater PUE for each tillage system
 226 compared to no N fertilizer application. Averaged across the 29-yr, PUE for CT wheat was 68 kg ha⁻¹ cm⁻¹ when no N
 227 fertilizer was applied and 102 kg ha⁻¹ cm⁻¹ when N was applied at 67 kg N ha⁻¹. Similarly, grain sorghum PUE under the
 228 CT system ranged from 141 kg ha⁻¹ cm⁻¹ for the control to 180 kg ha⁻¹ cm⁻¹ when was 60 kg N ha⁻¹ applied (Fig. 5). At
 229 lower N rates, PUE under CT and RT systems were always greater than NT. However, at 67 kg N ha⁻¹, PUE were similar
 230 in all tillage systems for both wheat and grain sorghum (Fig.5).

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233 Fig. 5. Tillage and nitrogen application effects on (a) winter wheat and (b) sorghum precipitation use efficiency. Data are
 234 averaged across years (29-yr for wheat and 28-yr for sorghum) and four replicates. Error bars represent one standard
 235 error of the mean. Means followed by the same letter (s) within N rate are not significantly ($P > 0.05$) different.
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239 **4. CONCLUSION**

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241 The results of this long-term study showed that tillage and N fertilizer application interacts to affect wheat and grain
 242 sorghum yields. In most years, grain yields for RT plots were equal or greater than CT at each N rate. Grain yields and
 243 PUE with NT were significantly lower than CT and RT particularly when N application rates were low. However, yields
 244 were not different among the tillage treatments at the highest N rate. Growers adopting NT practices may need to apply
 245 additional N fertilizer (~ 20 kg N ha⁻¹) to improve grain yields and PUE. The significantly greater yields and PUE at 67 kg N
 246 ha⁻¹ compared to the lower N rates suggests that higher N application rates (> 67 kg N ha⁻¹ in the current study) may be
 247 required to maximize both wheat and grain sorghum yields with any of the tillage systems.
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REFERENCES

1. Stone LR, Schlegel AJ. Yield-water supply relationships of grain sorghum and winter wheat. *Agron. J.* 2006; 98:1359-1366.
2. Haas HJ, Willis WO, Bond J.J. Summer fallow in the western United States. In: USDA Conserv. Res. Rep. 1974; 17. U.S. Gov. Print. Office, Washington, DC. p. 2-35.
3. Bowman RA, Vigil MF, Nielsen DC, Anderson RL. Soil organic matter changes in intensively cropped dryland Systems. *Soil Sci. Soc. Am. J.* 199; 63:186-19.
4. Campbell CA, Langford GP, Leyshon AJ, Zentner RP, Janzen HH. Effect of cropping practices on the initial potential rate of N mineralization in a thin Black Chernozem. *Can J. Soil Sci.* 1991; 71:43-53.
5. Peterson GA, Halvorson AD, Havlin JL, Jones OR, Lyon DG, Tanaka DL. Reduced tillage and increasing cropping intensity in the Great Plains conserve soil carbon. *Soil Tillage Res.* 1998;47:207-218.
6. Nielsen DC, Vigil MF. Precipitation storage efficiency during fallow in wheat-fallow systems. *Agron. J.* 2010; 102:537-543.
7. DeVuyst EA, Halvorson AD. Economics of annual cropping versus crop-fallow in the Northern Great Plains as influenced by tillage and nitrogen. *Agron. J.* 2004; 96:148-153.
8. Dhuyvetter KC, Thompson CR, Norwood C.A, Halvorson AD. Economics of dryland cropping systems in the Great Plains: a review. *J. Prod. Agric.* 1996; 9:216-222.
9. Schlegel AJ, Grant CA, Havlin JL. Challenging approaches to nitrogen fertilizer recommendations in continuous cropping systems in the Great Plains. *Agron J.* 2005;97:391-398.
10. William R, Gordon VJ. Improving N use efficiency in cereal production. *Agron. J.* 1999; 93:358-363.
11. Halvorson AD, Nielsen DC, Reule CA. Nitrogen fertilization and rotation effects on no-till dryland wheat production. *Agron. J.* 2004;96:1196-1201.
12. Thompson CA, Whitney DA. Long-term tillage and nitrogen fertilization in a west central Great Plains wheat-sorghum-fallow rotation. *J. Prod. Agric.* 1998;11:253-359.
13. Varvel GE. Precipitation Use Efficiency of soybean and grain sorghum in monoculture and rotation. *Soil Sci. Soc. Am. J.* 1995;59:527-531.
14. SAS Institute (1999) SAS/STAT guide for personal computers .Version 6. SAS Inst, Cary, NC.
15. López-Bellido RJ, López-Bellido L. Efficiency of nitrogen in wheat under Mediterranean conditions: effect of tillage, crop rotation and N fertilization. *Field Crops Res.* 2001;71:31-46.
16. Halvorson AD, Black AL, Krupinsky JM, Merrill SD, Wienhold BJ, Tanaka DL. Spring wheat response to tillage system and nitrogen fertilization within a crop-fallow system. *Agron. J.* 2001;92: 288-294.
17. Camara KM, Payne WA, Rasmussen PE. Long-term effects of tillage, nitrogen, and rainfall on winter wheat yields in the Pacific Northwest. *Agron. J.* 2003; 95:828-835.
18. Locke MA, Hons FM. Effect of N rate and tillage on yield, N accumulation and leaf N concentration of grain sorghum. *Soil & Till. Res.* 1988;12:223-233.
19. Malhi SS, Nyborg M. 1990. Effect of tillage and straw on yield and N uptake of barley grown under different N fertility regimes. *Soil & Till. Res.* 1990;17:115-124.
20. Kolberg RL, NR Kitchen, Westfall DG, Peterson GA. Cropping intensity and nitrogen management impact of dryland no-till rotations in the semi-arid western Great Plains. *J. Prod Agric.* 1996; 9:517-522.
21. Staggenborg S, Whitney DA, Fjell DL, Shroyer JP. Seeding and nitrogen rates required to optimize winter wheat yields following grain sorghum and soybean. *Agron. J.* 2003;95:253-259.