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# No-tillage Improves Winter Wheat (*Triticum Aestivum* L.) Grain Nitrogen Use Efficiency

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**ABSTRACT**

Tillage practices are among the factors that affect soil quality as well as use efficiency of fertilizer nitrogen (N). Data consisting of 24-site-years from two long-term experiments 222 (E222) located in Stillwater and 502 (E502) located in Lahoma, Oklahoma were used in this study. Treatments included pre-plant N rates of 0, 45, 90, and 135 kg N ha$^{-1}$ at E222 and 0, 22.5, 45, 67, 90 and 112 kg N ha$^{-1}$ at E502. The objective was to evaluate the influence of no-tillage (NT) on grain N uptake and N use efficiency (NUE) of winter wheat (*Triticum aestivum* L.) relative to conventional tillage (CT). Generally, results indicated significantly higher grain N uptake and NUE under NT relative to CT. However, single-degree-of-freedom contrast at individual N rate indicated inconsistency in grain N uptake and NUE between experimental locations. Under both tillage practices, grain N uptake increased with N rate while NUE decreased as N rate increased. Overall, NUE and grain N uptake was 23% and 7.5% higher under NT compared to CT, respectively. Therefore, winter wheat farmers in the United States Central Great Plains currently practicing CT could improve the efficiency of the surface-applied fertilizer N and farm profitability by adopting NT.

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No-tillage; nitrogen use efficiency; grain N uptake; nitrogen; winter wheat

## Introduction

Increased fertilizer nitrogen (N) losses are associated with reduced farm revenue and pollution of soil, water, and air. This is mainly because of the dynamic nature of fertilizer N within the soil system. Various approaches, at field scale and regional levels, have been suggested to reduce fertilizer losses and/or pollution of an agricultural ecosystem (Omara et al. 2017). Generally, sustainable farming practices such as conservation tillage have been advocated to improve resource use efficiency including fertilizer N (Omara et al. 2019; Rigby and Cáceres 2001; Tilman et al. 2002).

No-tillage (NT) is believed to be one of the farming practices that have significant influence on the grain nitrogen use efficiency (NUE) of applied N fertilizers in comparison to conventional tillage (CT). Many research reports have however indicated inconsistencies with both positive and negative impacts of NT on grain NUE (Rao and Dao 1996; Rozas, Studdert, and Andrade 1999; Licht and Al-Kaisi 2005; Liu et al., 2015). In general, it appears that the inconsistent findings are due to differences in fertilizer N method of application, type of crop and other environmental variables or site specific conditions that may positively or negatively influence N availability in the soil.

Reports demonstrating low NUE under NT are associated with volatilization losses from surface-applied urea. Rozas, Studdert, and Andrade (1999) reported a decrease in crop yield as a result of reduced NUE. Sometimes, volatilization of the total surface-applied urea can be as high as 50% (Sommer, Schjoerring, and Denmead 2004). While comparing volatilization losses between CT and

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NT, Bacon and Freney (1989) reported volatilization of surface-applied urea under NT at 24% but was negligible under CT. Rochette et al. (2009) explained that the high volatilization losses of urea are, in part, due to the presence of residue and associated high urease activity on the surface of NT fields. In a trial consisting of 4-site-years of data, Licht and Al-Kaisi (2005) did not observe any difference between NUE for CT and NT. In the same study, injecting liquid fertilizer N seems to have reduced N losses. Therefore, volatilization losses of N are in most cases due to broadcast urea.

On the other hand, enhancement of NUE under NT is mainly due to its ability to reduce N fertilizer runoff. Nitrogen losses through fertilizer runoff from the total N applied have been reported between 1% and 13% (Raun and Johnson 1999). Generally, runoff losses are lower under NT compared to CT. By reducing the rate of fertilizer runoff, NT significantly improves the use efficiency of the applied fertilizer N. Fertilizer loss due to volatilization when urea is applied to the surface without incorporation are generally greater with increasing soil pH. This implies that the surface mulch covering the soil coupled with the right method of N application can reduce volatilization losses by lowering soil pH (Billeaud and Zajicek 1989). Additionally, NT was reported to improve winter wheat (*Triticum aestivum* L.) grain yield by 32% after banding 60 kg N ha$^{-1}$ at 10 cm below the seed row compared to broadcast urea (Rao and Dao 1996). Seed drilling should be accompanied with N banding in order to improve NUE under NT.

At the time of the establishment of these experiments, NT was not popular as research reports documenting its benefits were limited. Therefore, both experiments 222 and 502 were initiated under CT. Many research articles in the 1990s and early 2000 indicated the superiority of NT over CT in improving crop yield and soil properties. This prompted a widespread adoption by a significantly large number of farmers all over the United States, especially those in the Great Plains (Hansen et al. 2012; Mikha, Vigil, and Benjamin 2013). Consequently, the conversion of these long-term experiments from CT to NT took place in 2011 when CT was stopped in 2010 (Aula et al. 2016). The objective of this study was to evaluate the influence of NT on grain N uptake and NUE relative to CT in winter wheat.

## Materials and methods

### Experimental site description

Data consisting of 24-site-years from long-term experiments; experiment 222 (E222), and 502 (E502) were used in this study. The E222 trial was established in 1969 on a well-drained, deep and slowly permeable Kirkland silt loam (fine, mixed, thermic Udertic Paleustoll) at the Agronomy Research Station in Stillwater, Oklahoma with an altitude of 272 masl. Experiment 502 was established in 1970 on a well-drained, deep and moderately permeable Grant silt loam (fine-silty, mixed, thermic Udic Argiustoll) at the North Central Research Station in Lahoma, Oklahoma with an altitude of 396 masl. Total rainfall and average air temperature were computed for both locations for the winter wheat growing periods from October to June (Figure 1). Since these data were taken from long-term experiments, several winter wheat varieties were used. These included Overley, Iba, Bullet, Billings, Endurance, Rubylee and Bullet at E502 and Doublestop-CL, Iba, GoLead, P2174, Endurance, Centerfield, OKField and OK9935C at E222.

### Experimental design and management

A randomized complete block with 13 treatments and four replications was used at E222. Four of the 13 treatments used in this report were 1, 2, 3, and 4 with 0, 45, 90, and 135 kg N ha$^{-1}$, respectively (Table 1). For each treatment, phosphorus (P) and potassium (K) rates were fixed at 29 and 37 kg ha$^{-1}$, respectively. Fertilizer N was applied as urea (46–0–0) pre-plant. Treatment 4 with the maximum N rate (135 kg ha$^{-1}$) was split, 67.5 kg ha$^{-1}$ pre-plant and another 67.5 kg ha$^{-1}$ applied mid-season. Triple superphosphate (0-22-0) and potassium chloride (0-0-52) were applied pre-plant as sources of P and K, respectively.

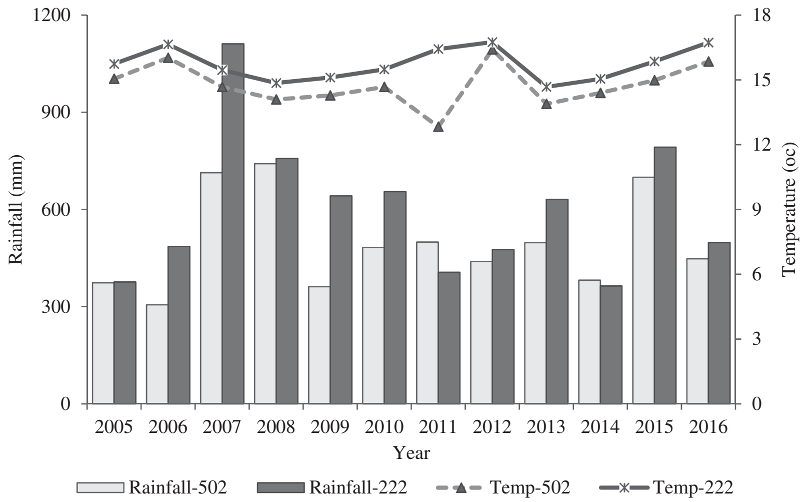


**Figure 1.** Total rainfall (October–June) and average air temperature (October–June) at E222 (Stillwater) and E502 (Lahoma), Oklahoma, 2003–2017.

**Table 1.** Treatment structure with pre-plant N, P and K rates at experiment 222 in Stillwater, Oklahoma.

| Treatment | N rate (kg N ha$^{-1}$) | P rate (kg P ha$^{-1}$) | K rate (kg K ha$^{-1}$) |
|---|---|---|---|
| 1† | 0 | 29 | 37 |
| 2† | 45 | 29 | 37 |
| 3† | 90 | 29 | 37 |
| 4† | 135‡ | 29 | 37 |
| 5 | 90 | 0 | 37 |
| 6 | 90 | 15 | 37 |
| 7 | 90 | 44 | 37 |
| 8 | 90 | 29 | 0 |
| 9 | 90 | 29 | 74 |
| 10 | 0 | 0 | 0 |
| 11 | 135‡ | 44 | 74 |
| 12 | 135‡ | 44 | 0 |
| 13 | 90 | 29 | 37 |

N, P, and K – Nitrogen, Phosphorus, and Potassium applied as Urea (46-0-0), Triple Super Phosphate (0-22-0) and Potassium Chloride (0-0-52), respectively.
†1–4, Treatments used in this study because they all have constant P and K rates.
‡N rate split to 67.5 N kg applied in Fall and 67.5 N kg applied in Spring.

Experimental design at E502 was a randomized complete block with 14 treatments and four replications. Six treatments used in this report included 2, 3, 4, 5, 6 and 7 with 0, 22.5, 45, 67, 90, and 112 kg N ha$^{-1}$, respectively (Table 2). The fertilizer rate of P and K were fixed at 20 and 56 kg ha$^{-1}$, respectively, for each treatment. Urea (46-0-0), triple superphosphate (0-22-0), and potassium chloride (0-0-52) were applied pre-plant as sources of N, P and K, respectively.

Both trails were established as a continuous winter wheat-summer fallow under CT system until 2010 and are presently managed under NT (Aula et al. 2016). Under CT, disc harrow and chisel plow were used in the preparation of the trials prior to planting seeds while Roundup (Glyphosate) and WeedMaster (Dicamba: 12.4% and 2,4-D: 35.7%) herbicides were applied at a rate of 1 to 2 L ha$^{-1}$, depending on the weed pressure under the NT. Winter wheat seeds were drilled using the Great Plains 2010 Drill (Great Plains Ag, Salina-Kansas, USA). Planting dates varied from 1 year to another

**Table 2.** Treatment structure with pre-plant N, P and K rates at experiment 502 in Lahoma, Oklahoma.

| Treatment | N rate (kg N $ha^{-1}$) | P rate (kg P $ha^{-1}$) | K rate (kg K $ha^{-1}$) |
|---|---|---|---|
| 1 | 0 | 0 | 0 |
| 2† | 0 | 20 | 56 |
| 3† | 22 | 20 | 56 |
| 4† | 45 | 20 | 56 |
| 5† | 67 | 20 | 56 |
| 6† | 90 | 20 | 56 |
| 7† | 112 | 20 | 56 |
| 8 | 67 | 0 | 56 |
| 9 | 67 | 10 | 56 |
| 10 | 67 | 29 | 56 |
| 11 | 67 | 39 | 56 |
| 12 | 67 | 29 | 0 |
| 13 | 112 | 39 | 56 |
| 14 | 67 | 20 | 56 |

N, P, and K – Nitrogen, Phosphorus, and Potassium applied as Urea (46-0-0), Triple Super Phosphate (0-22-0) and Potassium Chloride (0-0-52), respectively.
†2–7, Treatments used in this study because they all have constant P and K rates.

but seeds were generally drilled in October of each year reported in this study (2005 to 2016). Experimental fields were managed under rain-fed conditions with no irrigation water applied.

### *Sampling and sample processing*

The data used to determine grain N uptake was obtained from 2005 to 2010 under CT and 2011 to 2016 under NT. A Massey Ferguson 8XP self-propelled combine was used to harvest experimental plots at maturity. Wheat grain yields were adjusted to 12.5% moisture content. Grain samples were oven-dried for 48 h at 65°C and later ground to pass a 1 mm sieve. Grain N determination was completed using LECO Truspec CN dry combustion analyzer LECO CN628 at 950°C (Schepers, Francis, and Thompson 1989). Grain N uptake was then determined by multiplying percent N with grain yield. Using the difference method, NUE was computed from grain N uptake using the following equation (Eq. (1)).

$$NUE = \frac{Grain\ N\ uptake\ (fertilized\ plot) - Grain\ N\ uptake\ (check\ plot)}{Total\ N\ applied} \times 100 \qquad (1)$$

### *Statistical analysis*

The SAS statistical software package was used in the analysis of data (SAS Institute, 2013). The GLM procedure was used to conduct the analysis of variance for mean grain N uptake and NUE. Treatment means of grain N uptake and NUE at respective N rates between CT and NT were compared using single-degree-of-freedom orthogonal contrasts (Abdi and Williams 2010; Nogueira 2004). Grain N uptake was reported in kg $ha^{-1}$ while grain NUE was reported in percent (%). Treatment means were compared using Tukey's HSD test.

## Results and discussion

### *Grain N uptake*

The overall analysis of variance indicated significant differences in grain N uptake between treatment, tillage, and variety at both locations (Table 3). The treatment by tillage interaction was significant at E222 ($p$ = .031) but not at E502 ($p$ = .848). Grain N uptake generally increased with N rate under both CT and NT at E222 (Table 4). The lowest grain N uptake of 28 and 27.2 kg $ha^{-1}$

**Table 3.** F statistics for the effect of treatment, tillage, variety, and treatment by tillage interaction on grain N uptake (kg ha$^{-1}$) and NUE (%).

| Factor | D.F | Grain N Uptake | | NUE | |
|---|---|---|---|---|---|
| | | F | P | F | P |
| E222 | | | | | |
| Treatment | 3 | 71.24 | < .0001 | 3.9 | 0.0232 |
| Tillage | 1 | 68.57 | < .0001 | 15.8 | 0.0001 |
| Variety | 7 | 110.61 | < .0001 | 7.71 | < .0001 |
| Treatment x Tillage | 3 | 3.04 | 0.0309 | 1.11 | 0.3323 |
| E502 | | | | | |
| Treatment | 5 | 59.04 | < .0001 | 348.39 | < .0001 |
| Tillage | 1 | 21.54 | < .0001 | 2.47 | 0.1176 |
| Variety | 5 | 22.37 | < .0001 | 5.4 | 0.0001 |
| Treatment x Tillage | 5 | 0.4 | 0.8478 | 0.29 | 0.8858 |

E222, experiment number 222; E502, experiment number 502; N, Nitrogen; NUE, nitrogen use efficiency; D.F, degrees of freedom.

**Table 4.** Treatment means for Grain N uptake (kg ha$^{-1}$) and NUE (%) and single-degree-of-freedom orthogonal contrasts between CT and NT treatments at E222 (Stillwater), Oklahoma. 2005–2016.

| Treatment | Tillage | N rate (kg ha$^{-1}$) | Grain N Uptake (kg ha$^{-1}$)† | NUE (%) ‡ |
|---|---|---|---|---|
| Treatment means | | | | |
| 1 | CT | 0 | 28.0$^{B}$ | - |
| 2 | CT | 45 | 35.5$^{BA}$ | 16.8$^{A}$ |
| 3 | CT | 90 | 41.4$^{A}$ | 14.9$^{A}$ |
| 4 | CT | 135 | 46.4$^{A}$ | 13.7$^{A}$ |
| 1 | NT | 0 | 27.2$^{c}$ | - |
| 2 | NT | 45 | 40.8$^{B}$ | 30.2$^{A}$ |
| 3 | NT | 90 | 48.6$^{BA}$ | 24.6$^{BA}$ |
| 4 | NT | 135 | 54.3$^{A}$ | 20.0$^{B}$ |
| Contrast *p*-values | | | | |
| 1 | CT1 vs NT1 | 0 | 0.9022 | - |
| 2 | CT2 vs NT2 | 45 | 0.3553 | 0.001 |
| 3 | CT3 vs NT3 | 90 | 0.1653 | 0.0166 |
| 4 | CT4 vs NT4 | 135 | 0.1737 | 0.1141 |
| Average | CT vs NT | | 0.0467 | < .0001 |

CT = conventional tillage, NT = no-tillage, NUE = nitrogen use efficiency.
†Treatment means for grain N uptake were obtained under CT (2005–2010) and NT (2011–2016).
‡Treatment means for NUE were obtained under CT (2005–2010) and NT (2011–2016).
For each tillage practice, treatment means within the same column with different letters indicate significant differences at $p < .05$; Tukey's HSD test.

were recorded in check plots under CT and NT, respectively. Under CT, grain N increased by 21%, 14%, and 11% from application rate of 0 to 45, 45 to 90, and 90 to 135 kg N ha$^{-1}$, respectively. The percent incremental differences from 0 to 45, 45 to 90, and 90 to 135 kg N ha$^{-1}$ under NT were 33%, 16%, and 11%, respectively. Although grain N appeared generally to be higher under NT, orthogonal contrast analysis between CT and NT at this location (E222) did not show any significant differences at individual N application rates. Overall average grain N under NT was significantly higher than CT by 13% ($p$ = .047), possibly due to improved soil chemical properties that resulted to better utilization of the applied fertilizer N under NT relative to CT.

At E502, a similar pattern in grain N uptake was observed where grain N increased with fertilizer application rate (Table 5). The lowest grain N of 37.2 and 31.8 kg ha$^{-1}$ were observed in check plots under CT and NT, respectively. The highest grain N uptake was registered at an application rate of 112 kg N ha$^{-1}$ and was 51% and 55% more than that in check plots under NT and CT, respectively. Generally, grain N uptake was greater under CT compared to NT at individual N rates. While this was true, contrasting grain N uptake at respective N rate between CT and NT did not show any significant difference. The same observation was made for the overall contrast analysis ($p$ = .369).

**Table 5.** Treatment means for Grain N uptake (kg $ha^{-1}$) and NUE (%) and single-degree-of-freedom orthogonal contrasts between CT and NT treatments at E502 (Lahoma), Oklahoma. 2005–2016.

| Treatment | Tillage | N rate (kg $ha^{-1}$) | Grain N Uptake (kg $ha^{-1}$)† | NUE (%)‡ |
|---|---|---|---|---|
| Treatment means | | | | |
| 2 | CT | 0 | 37.2$^{E}$ | |
| 3 | CT | 22.5 | 46.1$^{ED}$ | 46.7$^{A}$ |
| 4 | CT | 45 | 55.5$^{CD}$ | 41.3$^{A}$ |
| 5 | CT | 67 | 60.7$^{CB}$ | 36.0$^{A}$ |
| 6 | CT | 90 | 68.4$^{B}$ | 38.4$^{A}$ |
| 7 | CT | 112 | 82.6$^{A}$ | 41.1$^{A}$ |
| 2 | NT | 0 | 31.8$^{D}$ | |
| 3 | NT | 22.5 | 42.7$^{C}$ | 48.6$^{A}$ |
| 4 | NT | 45 | 50.4$^{C}$ | 41.5$^{A}$ |
| 5 | NT | 67 | 61.4$^{B}$ | 42.2$^{A}$ |
| 6 | NT | 90 | 71.5$^{A}$ | 44.1$^{A}$ |
| 7 | NT | 112 | 78.9$^{A}$ | 42.1$^{A}$ |
| Contrast *p*-values | | | | |
| 2 | CT1 vs NT1 | 0 | 0.5509 | |
| 3 | CT2 vs NT2 | 22.5 | 0.5162 | 0.3171 |
| 4 | CT3 vs NT3 | 45 | 0.3263 | 0.5327 |
| 5 | CT4 vs NT4 | 67 | 0.9038 | 0.4839 |
| 6 | CT5 vs NT5 | 90 | 0.5722 | 0.6968 |
| 7 | CT6 vs NT6 | 112 | 0.4803 | 0.7909 |
| Average | CT vs NT | | 0.3688 | 0.7121 |

CT = conventional tillage, NT = no-tillage, NUE = nitrogen use efficiency.
†Treatment means for grain N uptake were obtained under CT (2005–2010) and NT (2011–2016).
‡Treatment means for NUE were obtained under CT (2005–2010) and NT (2011–2016).
For each tillage practice, treatment means within the same column with different letters indicate significant differences at $p < .05$; Tukey's HSD test.

The lack of differences in grain N uptake between NT and CT at E502 was similar to observations of previous studies (Thomsen and Sorensen, 2006; Constantin et al. 2010). Licht and Al-Kaisi (2005) also did not observe any differences in N uptake between NT and chisel plow. In the current study, the differential response of tillage practices in N uptake between experimental locations was probably due to substantial precipitation in late winter or early spring that could have increased nitrate-leaching losses. Over the study period, E222 received 104 mm of rainfall more than E502. Consequently, NT advantage in a low yielding environment was evident.

### *Nitrogen use efficiency*

Overall analysis of variance indicated a significant effect of treatment (N rate), tillage and variety on NUE while treatment by tillage interaction was not significant at E222 (Table 3). At E502, analysis of variance showed significant differences in NUE due to treatment, and variety while tillage as well as the treatment by tillage interaction was not significant (Table 3). Results showed that NUE was significantly different at the different fertilizer N rates in E222 under NT while no significant differences were observed under CT (Table 4). As was expected, NUE decreased with increasing N rate under both tillage practices. Nitrogen use efficiency decreased by 11% and 8% from 45 to 90 and 90 to 135 kg N $ha^{-1}$, respectively, under CT. Observations under NT indicated a decrease of 20% and 16% between application rate of 45 to 90 and 90 to 135 kg N $ha^{-1}$. Generally, NUE was higher under NT compared to CT (Table 4). Orthogonal contrast analysis at the same N rate indicated that NUE was significant with application of 45 kg N $ha^{-1}$ ($p$ = .001) and 90 kg N $ha^{-1}$ ($p$ = .0166) while no significant differences were observed between CT and NT at an application rate of 135 kg N $ha^{-1}$. An overall orthogonal contrast analysis indicated significant difference in NUE between NT and CT ($p < .0001$) with the former being 39% higher than the latter.

At E502, NUE at different N application rates were not significantly different under both tillage practices (Table 5). Although there was a tendency for NUE to decrease with increasing fertilizer N rate, no clear pattern was present under both CT and NT. For instance, the lowest NUE of 36% under CT was observed at fertilizer rate of 67 kg N $ha^{-1}$ compared to 41.1% at 112 kg N $ha^{-1}$. Similar observations were made under NT where the lowest NUE was not observed at the highest fertilizer N rate. Orthogonal contrast between CT and NT did not indicate significant differences in NUE between the two practices at this location ($p$ = .712). Nevertheless, NUE under NT exceeded NUE under CT by approximately 7%. This result did not mirror observations at E222 where a significant decrease in NUE occurred with increasing N rate.

Mechanisms for the improvement of NUE under NT relative to CT have been previously explained by many scholars. Raun and Johnson (1999) indicated that NT improves the use efficiency of the applied fertilizer N by reducing losses of fertilizer in runoff. Similarly, Cassman, Dobermann, and Walters (2002) added that NT improves N utilization by reducing erosion that can ultimately help reduce N runoff to surface waters. From another perspective, NT is believed to improve NUE through the beneficial action of arbuscular mycorrhizal fungi on N uptake efficiency, with regards to both soil N availability and N transfer to the host plant (Verzeaux et al. 2017). Hu et al. (2015) observed that NT increased the external mycorrhizal mycelium length relative to CT in a maize-wheat rotation. The reduced physical disturbance of the topsoil under NT stimulates an increase in propagule density leading to better colonization by the fungi relative to CT (Verzeaux et al. 2017).

Dalal et al. (2011) did not observe any difference in NUE between CT and NT in a vertisol soil. The authors explained that the insignificant tillage effect on NUE could have been due to the shrink-swell/cracking properties of vertisol soil which minimizes the nutrient stratification associated with NT. In the same study (Dalal et al. 2011), residue management had a significant impact on NUE. Compared to ‘residue burned’, NT with ‘residue retained’ showed greater NUE under a low rate of fertilizer N application.

Fredrickson, Koehler, and Cheng (1982) recovered more of the applied $^{15}N$-labeled fertilizer under NT relative to CT when ammonium sulfate was used as N source. In the current study, urea fertilizer, which is prone to volatilization loss, was used as a source of N. Similar to the present study, Yadvinder-Singh et al. (2009) observed inconsistency in results where differences in NUE between NT and CT depended on experimental locations with different soil types. The authors reported that NUE was 7% higher under NT compared to CT on a silt loam soil. On a sandy loam soil, NUE was 5% lower under NT compared to CT. Giller et al. (2004) indicated that NUE for rice was improved when NT drill was used to deep-place fertilizer N during planting. Therefore, the contribution of NT in improving NUE relative to CT seems depended on certain site-specific conditions.

### *Impact of varieties*

Several winter wheat varieties were used during the study period. Generally, both grain N uptake and NUE were significantly affected by varieties planted at both locations irrespective of the tillage practice (Table 6). At E502, comparison was made for the only variety (Bullet) planted under both tillage practices. Grain N uptake with the same variety ‘Bullet’ under NT was 36% higher than that under CT (Table 6). This observation was similar for NUE where the same variety ‘Bullet’ significantly performed better under NT compared to CT by 30.3%. Similar comparison was made at E222 for variety ‘Endurance’ that was planted under both tillage practices. The results mirrored observations at E502 where grain N uptake for ‘Endurance’ was 55.6% higher under NT compared to CT. Nitrogen use efficiency was also significantly higher under NT (27.8%) than under CT (10.9%) with the same variety ‘Endurance’. Comparisons of performance of other varieties were not possible since they were not uniformly planted under both tillage practices. The observations at both locations for varieties planted under both tillage practices generally indicate superiority of grain N uptake and NUE under NT compared to CT. Furthermore, it indicates that the observed differences were due to tillage effects rather than varieties used in this study. Several studies that

**Table 6.** Mean N uptake (kg $ha^{-1}$) and grain NUE (%) for winter wheat varieties used in the study at E502, Lahoma and E222, Stillwater, Oklahoma. 2005–2016.

| Tillage | Variety | N Uptake (kg $ha^{-1}$) | NUE (%) |
|---|---|---|---|
| E502 | | | |
| NT | Iba | $63.2^{BA}$ | $56.0^{A}$ |
| NT | Bullet | $56.1^{BA}$ | $38.6^{BC}$ |
| CT | Overley | $66.1^{A}$ | $45.1^{BA}$ |
| CT | Billings | $56.0^{BA}$ | $41.3^{B}$ |
| CT | Endurance | $52.2^{BC}$ | $39.7^{BC}$ |
| CT | Rubylee | $42.2^{DC}$ | $31.5^{BC}$ |
| CT | Bullet | $35.9^{D}$ | $26.9^{C}$ |
| E222 | | | |
| NT | Doublstop-CL | $62.7^{A}$ | $39.2^{A}$ |
| NT | Iba | $54.8^{BA}$ | $26.0^{CB}$ |
| NT | Endurance | $38.1^{C}$ | $27.8^{B}$ |
| NT | Centerfield | $29.6^{D}$ | $20.1^{DC}$ |
| NT | OK9935C | $17.7^{E}$ | $10.6^{D}$ |
| CT | GoLead | $53.8^{B}$ | $17.8^{D}$ |
| CT | P2174 | $53.2^{B}$ | $18.8^{DC}$ |
| CT | OKField | $27.4^{D}$ | $12.9^{D}$ |
| CT | Endurance | $16.9^{E}$ | $10.9^{D}$ |

E502, experiment number 502; E222, experiment number 222; N, nitrogen; NUE, nitrogen use efficiency; CT, conventional tillage; NT, no tillage.
Means with different letter superscripts in the same column under each location represent significant differences in NUE and grain N uptake between varieties at the $p < 0.05$ level, Tukey's HSD test.

report higher grain N uptake and NUE under NT relative to CT used similar varieties (Fredrickson, Koehler, and Cheng 1982; Giller et al. 2004; Yadvinder-Singh et al. 2009).

## Conclusion

The influence of NT on grain N uptake and NUE was investigated relative to CT. Results indicated an overall significant advantage of NT in improving grain N uptake and NUE although inconsistency was observed between experimental locations for grain N uptake. Grain N uptake increased with fertilizer N application rate while NUE decreased as N rate increased. Nitrogen use efficiency was 39% and 7% higher under NT compared to CT at E222 and E502, respectively. Grain N uptake was 4% higher under CT relative to NT at E502 while at E222, grain N uptake was 11.5% higher under NT compared to CT. Results averaged across locations show 23% and 7.5% higher NUE and grain N uptake under NT compared to CT, respectively. Winter wheat farmers in the United States Central Great Plains currently practicing CT could improve the efficiency of the surface-applied fertilizer N by adopting NT.

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