EFFECT OF TILLAGE AND ANHYDROUS AMMONIA APPLICATION ON NITROGEN USE EFFICIENCY OF HARD RED WINTER WHEAT

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ABSTRACT

Nitrogen use efficiency (NUE) is estimated to be 33% throughout the world, and can be lower when N is applied in single, pre-plant applications compared with split N applications. This study was conducted to evaluate tillage system and anhydrous ammonia application methods on yield, N uptake, and NUE in hard red winter wheat (*Triticum aestivum* L.), using a narrow (10 cm) nozzle spacing on a V-blade (Noble or sweep blade) applicator and wide (46 cm) nozzle spacing on a knife applicator. At Stillwater (Efaw) no significant differences between no-till and conventional-till treatments in grain yield were observed the initial year, however conventional tillage did obtain a significant advantage the second year. Grain N uptake was increased in conventional-till in consecutive years at Efaw, but no advantage occurred in NUE from either tillage system in either year. At Lahoma conventional tillage increased grain yield and grain N uptake in consecutive years compared to no-till. Conversely, no-till had a significant advantage for NUE both years. Based on two years of data, no-till when compared to conventional-till could be advantageous, and improve NUE. A trend for improved grain yield, grain N uptake, and NUE was noted for application

of anhydrous ammonia with a narrow nozzle spacing V-blade applicator over the more popular wider nozzle spacing knife applicator in conventional-till, but the trend was reversed with the knife applicator increasing grain yield, grain N uptake, and NUE over the V-blade applicator in no-till.

INTRODUCTION

Soil erosion has been a major concern since the beginning of agriculture, but it was not until the Great Dust Bowl of the 1930s that the problem received worldwide attention. With so many deaths caused by black pneumonia and total crop destruction by wind-borne soil in massive volumes, measures were taken to make sure that this would never happen again. Among those new practices was zero tillage. Zero tillage has been used as a means of annual crop production in most parts of the country for well over thirty years, but not in the Southern Great Plains. Anhydrous Ammonia (AA) as a nitrogen fertilizer source is very popular in winter wheat (*Triticum aestivum* L.) production in Oklahoma because of lower cost compared to other nitrogen fertilizers. Limited published research has been completed to show the effects of AA in winter wheat production in this area. This study was conducted to determine if tillage and AA application methods affect nitrogen use efficiency (NUE) of winter wheat in Oklahoma.

No-till was originally used as a method to stop soil erosion. Researchers found that planting crops in previous crop stubble greatly reduced the amount of soil removed by water and wind erosion. McGregor et al. (1992) reported that during a 5-year period (1987 through 1991), no-till soybean yielded 44% more than conventional-till yields. Intensive tillage has led to annual sediment discharge of 15.9 Mg ha^{-1} in the southern Great Plains (Smith et al., 1991). McGregor et al. (1992) reports indicated increasing soil losses with time under conventional-till and decreasing soil loses with time for no-till. This study conducted over 14 years; noted no-till yields exceeded those of conventional-till yields by 800 kg/ha yr^{-1} (McGregor et al., 1999). No-till reduced runoff 1 to 35% over conventional-till and reduced soil loss by 23 to 77% compared to conventional-till (McGregor et al., 1999). King et al., (1995), McIsaac et al., (1990), Pesant et al., (1987) and Lembi et al., (1985), similarly found that long-term no-till practices are effective and practical in reducing rill erodibility and sediment loss. Brenneman and Laflen (1982) and Cogo et al. (1984) concluded that residue cover reduces erosion in one of four ways: 1) dissipation of the energy from raindrop impact: 2) slowing runoff, and increasing flow depth, which in turn reduces the impact of raindrops: 3) absorption of some of the forces from runoff that are usually applied to the soil surface: and 4) creation of small reservoirs of ponded runoff causing deposition.

There have been several other unforeseen advantages of no-till over conventional-till that researchers have discovered over time. Edwards et al., (1990) found that no-till improved soil drainage, while Weersink et al., (1992) stated that no-till reduces labor costs. Aase and Pikul (1995) found that in annual spring wheat production, no-till was the most efficient crop and soil management practice from the standpoint of yield, water use efficiency, soil organic C, and bulk density. However, Mielke et al. (1986), Bruce et al. (1990), Rhoton et al. (1993), and Vyn and Raimbault (1993) have reported that bulk density increases under no-till versus conventional-till. Blevins et al. (1983), Unger (1991), and Ismail et al. (1994) reported that tillage had no effect on bulk density. Alternatively, Lal et al. (1994), Pikul and Aase, (1995), and Dao (1993) agreed with Aase and Pikul (1995) reporting that no-till reduced bulk density. After looking at these studies in great detail, it can be concluded that no-till can increase bulk density of soils by increasing soil compaction in saturated clay-textured soils, but in dry clay-textured soils as well as silt and sandy soils of any saturation level, bulk density will decrease with no-till compared to conventional-till. There have been other controversies comparing no-till to conventional-till systems as well as bulk density, one such argument being pH. Blevins et al. (1977) and Dick (1983) found that pH decreased under no-till as compared to conventional-till as nitrogen rates were increased, but Lal et al. (1994) found no effect of tillage on pH.

Research has indicated that soil organic matter content is related to amount of residue returned to the soil (Black, 1973: Campbell and Zentner, 1993; Eghball et al., 1994; Christensen et al., 1994). In the semiarid regions where dryland wheat is grown, soil organic carbon (C) and nitrogen (N) has declined with years of cultivation (Dodge and Jones, 1948; Haas et al., 1957; Hobbs and Brown, 1957; Young et al., 1960). This loss of soil organic C and N in the Great Plains has been caused by the use of tillage and summer fallow, which have accelerated organic matter decomposition rates and erosion (Ridley and Hedlin, 1968; Haas et al., 1957). Ismail et al. (1994), Lal et al. (1994), Christensen et al.

(1994), Unger (1991), and Wood et al. (1991) reported soil organic matter was greater under no-till and increased with time in some instances. Lamb et al. (1985) and Bauer and Black (1981) agreed with long-term studies where virgin soils were put under cultivation, losses of soil organic C and N were much higher for conventional-till than no-till systems. Allison (1973) found that most non-legume crops acquire 30 to 100% of their N nutritional needs from soil organic matter. Bauer and Black (1994) discovered that 1 Mg ha^{-1} of soil organic matter contributed the equivalent of 15.6 kg ha^{-1} of wheat grain yield. Doran (1980), Follett and Schimel (1989), Bakersman and deWit (1970) and Groffman, (1984) have reported that microbial activity is generally greater in the first few centimeters of soil under no-till as compared to conventional-till, resulting in reduced organic matter levels in conventional-till as compared to no-till systems. Tillage significantly reduces the diversity of bacteria by reducing both substrate richness and evenness (Lupwayi et al., 1998). Further comparisons showed that no-till enhanced N immobilization and reduced nitrification rates when compared to conventional-till (Doran, 1980; Stinner et al., 1983), often resulting in less nitrate leaching (Elliott et al., 1986; Lamb et al., 1985) and leaving less nitrate in the soil profile (Fenster and Peterson, 1979; Dowdell and Cannell, 1975). Although there are lower nitrate levels in soil profiles in no-till systems, studies have shown that nitrate has been found deeper in the profiles of no-till soils (Eck and Jones, 1992).

The results of a 10-year study have shown that N-mineralization rates were higher in annual cropping systems under no-till, than under conventional-till

(Wienhold and Halvorson, 1999). This increased mineralization is caused by increased N stored as labile organic forms. Increased amounts of organic N will supply more nitrogen to crops, which will result in less N required from fertilizers as well as reduced leaching. Wienhold and Halvorson (1999) also believe that higher N rates will increase immobilization because of the increased plant residue resulting from the higher N rates increasing the C/N ratio of the residue. Several other studies have shown that immobilization was higher at lower applied N rates and crop N uptake was less with no-till systems (Kitur et al., 1984; Smith and Sharpley, 1990; Wagger et al., 1985; Black and Reitz, 1972; Cochran et al., 1980; Elliot et al., 1986; Dowdell and Crees, 1980; Knowles et al., 1993; Rice and Smith, 1984). This research has also found evidence that immobilization of surface applied N fertilizers accounts for most of the differences in N response between no-till and conventional-till systems. Their research also shows that no-till systems required more N fertilizer when surface applied at lower rates. However, Fox and Bandel (1986) discovered that no-till increased mineralization compared to conventional-till during the latter part of the growing season. Rice and Smith (1982) and Rodriguez and Giambiagi (1995) found that no-till enhances denitrification, because of the increase in soil water supply commonly occurring in no-till, reducing the amount aerobic activity in the soil. There are some conflicting views between Wienhold and Halvorson (1999) and the others stated above, but keep in mind that the Wienhold and Halvorson (1999) study was long-term (10 years), while the others were short-term (5 years or less). Wienhold and Halvorson were the only ones to account for the build up of soil organic matter (OM), and it would not be possible for soil OM to be a major factor in a short-term study. Water use efficiency (WUE) is probably the most important advantage to no-till systems over conventional-till. Bonfil et al. (1999) found that no-till management over a 5-year study increased yields 62 to 67% in wheat-fallow rotations and 18 to 75% in continuous wheat over conventional-till in semiarid regions of Israel. Cantero-Martinez et al. (1999), Peterson et al. (1996), and Kolberg et al. (1996) all found similar results in Australia and the Great Plains of the United States. No-till increases WUE by reducing evaporation, increasing water infiltration, improving soil structure, which in turn enhances root development (Aase and Pikul, 1995; Holland and Felton, 1989; Jones and Popham, 1997; Norwood, 1994; Smika and Unger, 1986; Waddell and Weil, 1996; Kirkegaard et al., 1995; Merrill et al., 1996; Dao, 1993; Lopez-Bellido et al., 1996). Winter wheat is now being produced successfully and out-yielding spring wheat in the Northern Great Plains of the United States and Canada without requiring a fallow period, when no-till is used with adequate N fertilization (Halvorson et al., 1999; Entz and Fowler, 1991). By increasing stored water in the soil, no-till has reduced the detrimental effects of climate variability on annual winter wheat production (Dao, 1993).

Studies have shown that deep placement of N can minimize volatilization or immobilization losses. Placement of N is a major factor of N utilization and a 20% increase in NUE has been observed with band placement, compared to surface broadcast (Soper et al., 1971; Toews and Soper, 1978; Tomar and

Soper, 1981). They found that N immobilization and increased N uptake could be achieved by reducing fertilizer contact with the surface residue. Rao and Dao (1996) found that final grain yield and grain N content were not affected by N placement in plowed plots. No-till improved grain yield by 32% for a below the seed row (BL) application and 15% for between the rows (BT) application. Grain N content was increased by 33% for BL and 25% for BT as compared to a surface broadcast application.

Anhydrous ammonia has the highest amount of fixation of all the forms of ammonium releasing fertilizers (Young and Cattani, 1962). Since surface applications of ammonium-based N can be lost to the atmosphere by 70% from volatilization (Hamid and Mahler, 1994) and nitrate more readily leaches from the soil than ammonia (Blue and Eno, 1954), anhydrous ammonia (AA) has the most potential to increase NUE in single pre-plant applications. Some researchers have agreed that AA moves more in sandy soils with low CEC and low moisture than finer textured soils with high CEC, but under moist conditions and at depths over 10 cm, high rates of AA can be applied with little or no loss from volatilization (Swart et al., 1971; Baker et al., 1959; Blue and Eno, 1954; McDowell and Smith, 1958; Papendick and Parr, 1966). McDowell and Smith (1958) found that ammonia losses were reduced considerably when the applications were changed from 40-inch to 16-inch spacings. Swart et al. (1971) supported this research with his own findings that show differences between 102 cm and 41cm (greater yields and less ammonia loss at 41cm), but no differences between 15cm and 41cm. Swart et al. (1971) went on to report while vertical movement remains constant (4 to 5 cm) regardless of N rate, higher N rates usually cause greater lateral movement. Other research has suggested that AA decreases pH and depletes the amount exchangeable Ca and Mg leading to decreases in yield due to higher levels of aluminum accumulation (Bouman et al., 1995; Robbins and Voss, 1989). The objective of this experiment was to determine the effects of tillage and AA application rate and placement on grain yield, grain N, and NUE of hard red winter wheat.

MATERIALS AND METHODS

Two experimental sites were established in the fall of 2000, one near Stillwater, OK at the Agronomy Research Station (Easpur loam fine-loamy, mixed, superactive, thermic Fluventic Haplustoll), and one in Lahoma, OK at the North-Central Oklahoma Research Station (Grant silt loam fine-silty, mixed, thermic Udic Argiustoll). Initial soil test results are reported in Table 1. The experiment employed a randomized complete block design with three replications. Individual plots measured 3.0 x 4.6 m.

Anhydrous ammonia (82-0-0) was applied at rates of 61, 123, and 185 kg N ha^{-1} using two different methods of injection. A rolling coulter applicator (DMI) with five knives spaced 46 cm apart at a depth of 15 cm, a method commonly used in nitrogen application of winter wheat, was used as one method of AA application. The noble or undercutting blade (V-Blade), an experimental applicator, was used as the other method of AA application. The noble blade applicator has a single coulter, centered in front of the point of the undercutting blade, where AA was applied in 10-cm bands at a depth of 10 cm and a total width of 1.5 meters.

The winter wheat variety 'Jagger' was planted at both sites (planting and fertilizer dates are reported on Table 2). At the Lahoma site, a seeding rate of 95 kg ha^{-1} was planted the initial year and increased to 125 kg ha^{-1} the second year in 19-cm rows within wheat stubble from the previous year as well as conventionally worked ground. Triple super phosphate (0-20-0) (N-P-K) was applied pre-plant at a rate of 90 kg P ha^{-1} both years at Lahoma to alleviate possible phosphorus deficiencies. At the Efaw site, a rate of 125 kg ha^{-1} was planted in 15-cm rows in grain sorghum stubble from the previous summer as well as conventionally worked ground. In this case, conventional tillage at both sites consisted of plowing after wheat harvest, disking throughout the summer, and preparing the seedbed with a field cultivator. Wheat grain was harvested with a Massey Ferguson 8XP experimental combine, removing an area of 2.0 x 4.6 m from the center of each plot. A Harvest Master yield-monitoring computer installed on the combine was used to record yield data. Grain yield from each plot was determined and a sub-sample was taken for total N analysis. Grain samples were dried in a forced air oven at 66°C, ground to pass a 140 mesh sieve (100 um), and analyzed for total N content using a Carlo-Erba NA 1500 automated dry combustion analyzer (Schepers et al., 1989). Analyses of variance and single degree of freedom contrasts were performed using SAS (SAS, 1990). Response indices (RI) were calculated by dividing the highest N treated grain yield average by the check (0 N rate) average.

RESULTS AND DISCUSSION

Grain Yield

Due to delayed planting (Table 2), resulting in poor establishment and little to no tillering, wheat yield responses to applied N were minimal in 2001 at both locations. However, in 2002, increased wheat yields were obtained with earlier planting dates and good tiller development, while response to applied N was still limited. At Efaw a positive linear response to N using both applicators was observed in the no-till treatments both years (Table 3). A positive linear trend was also observed at Efaw with both applicators in the conventional till treatments in 2001 (Table 3). At Lahoma a positive linear trend was observed in the no-till plots with the knife applicator the initial year. Highly significant positive quadratic responses to N rate were observed at Lahoma both years for the V-blade applicator in no-till. Statistical analysis did detect a positive quadratic response to the knife applicator the second year at Lahoma in no-till. In 2002 a highly significant advantage was achieved from the V-blade applicator over the knife applicator in no-till at Lahoma. While there were no differences between tillage systems at Efaw the initial year, conventional tillage did result in a slight advantage at Efaw the second year. Similar advantages in yield were observed both years at Lahoma in conventional tillage. It could be speculated that the inconsistency in response to tillage between the two sites was caused by a better seed establishment obtained from the no-till treatments at Efaw being planted into the stubble of a grain sorghum cover crop that reduced soil crusting between wheat crops versus being planted into the previous year's wheat stubble. Although not specifically measured, increased N immobilization was likely present in no-till plots, since a highly significant interaction was found between tillage and N rate both years at Lahoma along with response indices (RI) values greater in all four site years when compared to conventional-till. However, the lack of an interaction at the Efaw site both years would indicate that the grain sorghum residue is less dense and less resistant to decomposition. This would suggest that the utilization of a summer annual cover crop could increase the effectiveness of a no-till tillage system in Oklahoma. The limited response to applied N in conventional-till and the moderate response no-till at Efaw and Lahoma both years elucidates the need for us to be able to recognize when the crop has the potential to respond to N.

Grain N Uptake

Grain N uptake was consistent with results for grain yield at both locations and both years; low the initial year as was grain yield and relativity high the second year. Positive linear responses to N rate were detected in both years at Efaw for both applicators and tillage systems (Table 4). At Lahoma, a positive linear response to N rate was discovered both years for the knife applicator in no-till, but was quadratic with the V-blade applicator in no-till. In 2001, knife application of AA increased grain N uptake over that of the V-blade in no-till at Efaw, but the V-blade increased grain N uptake over knife application of AA in conventional-till the second year. At Lahoma in 2002, knife application of AA had an advantage in conventional-till; conversely the V-blade had an advantage in no-till. Grain N uptake in the conventional tillage system was slightly higher than no-till at Efaw in both years (Table 4). However, there was a highly significant advantage found for grain N uptake under conventional tillage compared to no-till at Lahoma (Table 4). A significant interaction was found between tillage and N rate at Lahoma for grain N uptake, maintaining the consistency established in grain yield that immobilization did take place in the no-till plots.

Nitrogen Use Efficiency

Nitrogen use efficiency decreased with increasing N applied at both sites, both years, both tillage systems, and method of AA application. At Efaw, the knife applicator improved NUE over the V-blade in no-till the initial year, but the V-blade applicator increased NUE over knife applied AA in conventional-till the second year. In conventional-till at Lahoma, the V-blade applicator increased NUE over knife applied AA the initial year, while the knife increased NUE over the V-blade the second year. Higher NUE values were observed for the knife compared to V-blade applied AA in no-till the second year at Lahoma. A significant interaction between tillage and N method was detected both years at Efaw and the second year at Lahoma, further revealing that tillage practices did affect the efficiency of the applicators. In general, there was a trend for increased NUE with the knife application in the no-till tillage system.

CONCLUSIONS

Over the two-year period evaluated, conventional tillage significantly increased grain yield and grain N uptake over no-till at both sites, but, with no significant difference between tillage systems the initial year at Efaw and with the difference between tillage systems greatly reduced the second year at Efaw when no-till was used. While no-till resulted in lower grain yields and grain N uptake, it did improve NUE at one site year and was maintained at the other three locations compared to conventional-till. This suggests that the expected increase in immobilization in no-till increased the demand for N and improved NUE. The use of a V-blade applicator with a narrow band placement of N improved grain yield, grain N, and NUE consistently in conventional-till at three site years, but the V-blade applicator only improved grain yield and grain N uptake both years at Lahoma over the knife applicator in no-till. The knife applicator actually increased grain yield and grain N uptake both years in no-till at Efaw and NUE over the V-blade three of the four site years in no-till. This suggests that the V-blade applicator may be advantageous in conventional-till, but the knife applicator may be more beneficial in no-till. Further research in the use of summer cover crops to prevent soil erosion and crusting could improve the potential for no-till and conservational-till in Oklahoma.

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Table 1. Initial surface (0-15 cm) and sub-soil (15-30 cm) test results prior to experiment

initiation at Efaw and Lahoma OK.

Sample	NH_4-N	NO_3-N	P	K	pH
	------------------------------- mg kg^{-1} -------------------------------				
Lahoma (0-15 cm)	14.35	8.86	9.34	282	5.67
Lahoma (15-30 cm)	15.78	3.89	6.49	222	6.23
Efaw (0-15 cm)	15.87	11.16	28.23	225	5.70
Efaw (15-30 cm)	13.70	7.41	7.44	190	6.35

NH_4-N and NO_3-N – 2 M KCL extract; P and K – Mehlich-3 extraction; pH – 1:1 soil:deionized water

Table 2. Planting, fertilizer, and harvest dates at Efaw and Lahoma, OK, 2000-02.

Location	Crop Year	Planting	Fertilizer Application	Grain Harvest
Lahoma	2000-2001	11-27-00	11-27-00	6-14-01
Efaw	2000-2001	11-30-00	11-22-00	6-11-01
Lahoma	2001-2002	10-03-01	9-04-01	6-25-02
Efaw	2001-2002	10-01-01	9-11-01	6-21-02

Table 3. Grain yield treatment means and analysis of variance at Efaw and Lahoma, 2001-2002.

Treatment			Efaw		Lahoma	
			2001	2002	2001	2002
Tillage	App/ Source	N rate kg N ha^{-1}	Yield (Mg ha^{-1})			
CT	Knife	0	2.26	3.57	1.77	3.98
		61	2.27	3.59	2.13	4.29
		123	2.50	3.80	1.29	3.92
		185	2.53	3.64	2.07	3.86
	Avg.		2.39	3.65	1.82	4.01
	V-blade	0	2.13	3.71	1.90	3.65
		61	2.48	3.73	2.45	4.07
		123	2.63	3.99	1.70	3.80
		185	2.61	3.76	1.97	3.94
	Avg.		2.51	3.80	2.01	3.87
CT Response Indices (RI)			1.23	1.08	1.29	1.12
NT	Knife	0	1.90	2.98	1.12	1.85
		61	2.29	3.42	1.43	2.92
		123	2.55	3.66	1.54	2.97
		185	2.66	3.59	1.87	2.60
	Avg.		2.35	3.41	1.49	2.59
	V-blade	0	2.10	2.94	0.78	2.16
		61	2.11	3.11	1.68	3.33
		123	2.48	3.25	1.89	3.62
		185	2.44	3.67	1.66	3.59
	Avg.		2.28	3.24	1.50	3.18
NT Response Indices (RI)			1.40	1.25	1.67	1.68
SED			0.13	0.29	0.31	0.42

Source of Variation	df	Mean Squares			
Tillage	1	0.118	1.926*	1.789*	12.256***
Rep * Tillage (a)	4	0.158	1.217	0.414	0.445
N rate	3	0.476***	1.237**	0.652***	1.097***
N method	1	0.000	0.005	0.107	0.465**
N rate * N method	3	0.006	0.079	0.231	0.224
Tillage * N rate	3	0.017	0.511	0.753***	0.746***
Tillage * N method	1	0.086	0.303	0.058	1.608***
Tillage * N rate * N method	3	0.063	0.149	0.021	0.013
Error	28	0.034	3.073	0.094	0.109

CT, Knife vs. V-blade	1	NS	NS	NS	NS
NT, Knife vs. V-blade	1	*	NS	NS	***
CT, Knife linear	1	*	NS	NS	NS
NT, Knife linear	1	***	*	**	*
CT, Knife quadratic	1	NS	NS	NS	NS
NT, Knife quadratic	1	NS	NS	NS	*
CT, V-blade linear	1	**	NS	NS	NS
NT, V-blade linear	1	**	**	***	***
CT, V-blade quadratic	1	NS	NS	NS	NS
NT, V-blade quadratic	1	NS	NS	***	***

*, **, *** Significant at the 0.10, 0.05, and 0.01 levels of probability, respectively; NS is not significant. SED is the standard error of the difference between two equally replicated means.

Mean squares not followed by a symbol are not significant. CT= conventional tillage; NT= no-till

RI = highest N treated grain yield average divided by the check (0 N rate) average.

Table 4. Grain N uptake treatment means and analysis of variance at Efaw and Lahoma, 2001-2002.

Tillage	App/ Source	N rate kg N ha^{-1}	Efaw 2001	Efaw 2002	Lahoma 2001	Lahoma 2002
			Grain N uptake (kg ha^{-1})			
CT	Knife	0	55.9	88.7	41.8	101.6
		61	58.1	91.3	50.4	114.6
		123	66.8	98.7	33.8	116.3
		185	65.5	99.7	52.7	111.1
	Avg.		61.6	94.6	44.7	110.9
	V-blade	0	49.4	76.8	43.0	92.8
		61	61.9	102.7	60.3	111.1
		123	67.6	109.4	46.2	96.9
		185	69.6	104.5	51.7	102.7
	Avg.		62.1	98.4	50.3	100.9
NT	Knife	0	41.6	69.3	23.9	52.7
		61	53.5	81.9	34.0	71.2
		123	69.3	91.5	38.6	77.6
		185	69.9	92.1	47.8	68.8
	Avg.		58.6	83.7	36.1	67.6
	V-blade	0	46.1	66.3	16.6	34.1
		61	48.7	69.4	43.4	84.3
		123	57.8	82.3	45.8	96.1
		185	59.5	103.8	46.1	101.0
	Avg.		53.0	80.5	38.0	78.9
SED			4.9	10.3	7.9	14.0
Source of Variation		df	Mean Squares			
Tillage		1	398.43*	2699.87*	1070.07	10920.12***
Rep * Tillage (a)		4	148.72	506.30	367.16	323.92
N rate		3	730.06***	1389.11***	664.55***	1561.70***
N method		1	75.00	0.79	157.86	33.04
N rate * N method		3	14.37	130.80	159.77	256.85*
Tillage * N rate		3	26.93	154.19	354.84**	656.93***
Tillage * N method		1	150.33*	157.28	28.00	1452.76***
Tillage * N rate * N method		3	79.57	221.27	8.83	378.58**
Error		28	38.29	127.75	72.70	113.96
CT, Knife vs. V-blade		1	NS	*	NS	**
NT, Knife vs. V-blade		1	**	NS	NS	***
CT, Knife linear		1	**	NS	NS	NS
NT, Knife linear		1	***	*	**	*
CT, Knife quadratic		1	NS	NS	NS	NS
NT, Knife quadratic		1	NS	NS	NS	*
CT, V-blade linear		1	***	***	NS	NS
NT, V-blade linear		1	**	***	***	***
CT, V-blade quadratic		1	NS	**	NS	NS
NT, V-blade quadratic		1	NS	NS	**	***

*, **, *** Significant at the 0.10, 0.05, and 0.01 levels of probability, respectively; NS is not significant.
SED is the standard error of the difference between two equally replicated means.
Mean squares not followed by a symbol are not significant.
CT= conventional tillage; NT= no-till

Table 5. Nitrogen Use Efficiency treatment means and analysis of variance at Efaw and Lahoma, 2001-2002.

Treatment			Efaw		Lahoma	
			2001	2002	2001	2002
Tillage	App/ Source	N rate kg N ha^{-1}	NUE (%)			
CT	Knife	61	8.9	13.9	13.2	28.5
		123	11.5	13.0	-7.0	15.6
		185	6.9	9.1	5.6	7.5
	Avg.		9.1	12.0	3.9	17.2
	V-blade	61	15.0	32.6	29.4	22.8
		123	12.1	21.6	3.1	-0.2
		185	9.1	11.7	5.0	3.0
	Avg.		12.1	22.0	12.5	8.5
NT	Knife	61	15.9	23.1	22.6	17.1
		123	20.7	19.3	15.0	11.3
		185	14.1	11.2	14.9	10.3
	Avg.		16.9	17.9	17.5	12.9
	V-blade	61	8.1	2.6	38.1	15.1
		123	11.4	11.8	20.8	9.8
		185	8.5	19.4	14.0	3.4
	Avg.		9.3	11.3	24.3	9.4
SED			4.2	8.8	6.1	6.4
Source of Variation		df	Mean Squares			
Tillage		1	0.57	0.44	14.52*	57.00**
Rep * Tillage (a)		4	0.43	3.40	2.31	3.28
N rate		2	0.55	0.58	11.53***	23.47***
N method		1	0.47	0.14	5.34**	1.93
N rate * N method		2	0.10	0.21	2.06	0.58
Tillage * N rate		2	0.15	2.13	1.16	1.50
Tillage * N method		1	2.52**	7.56*	0.07	15.98***
Tillage * N rate * N method		2	0.07	2.96	0.03	0.15
Error		20	0.40	1.80	0.83	0.91
CT, Knife vs. V-blade		1	NS	**	*	*
NT, Knife vs. V-blade		1	**	NS	NS	***
CT, Knife linear		1	NS	NS	**	**
NT, Knife linear		1	NS	NS	NS	***
CT, Knife quadratic		1	NS	NS	NS	NS
NT, Knife quadratic		1	NS	NS	NS	NS
CT, V-blade linear		1	NS	***	***	**
NT, V-blade linear		1	NS	NS	***	***
CT, V-blade quadratic		1	NS	NS	*	*
NT, V-blade quadratic		1	NS	NS	NS	NS

*, **, *** Significant at the 0.10, 0.05, and 0.01 levels of probability, respectively; NS is not significant.
NUE= (Grain N uptake of N treatment – Grain N uptake of check) / N rate
SED is the standard error of the difference between two equally replicated means.
Mean squares not followed by a symbol are not significant.
CT= conventional tillage; NT= no-till

APPENDIX

Figure 1. Relationship between grain yield and grain N uptake at Efaw and Lahoma, 2001.

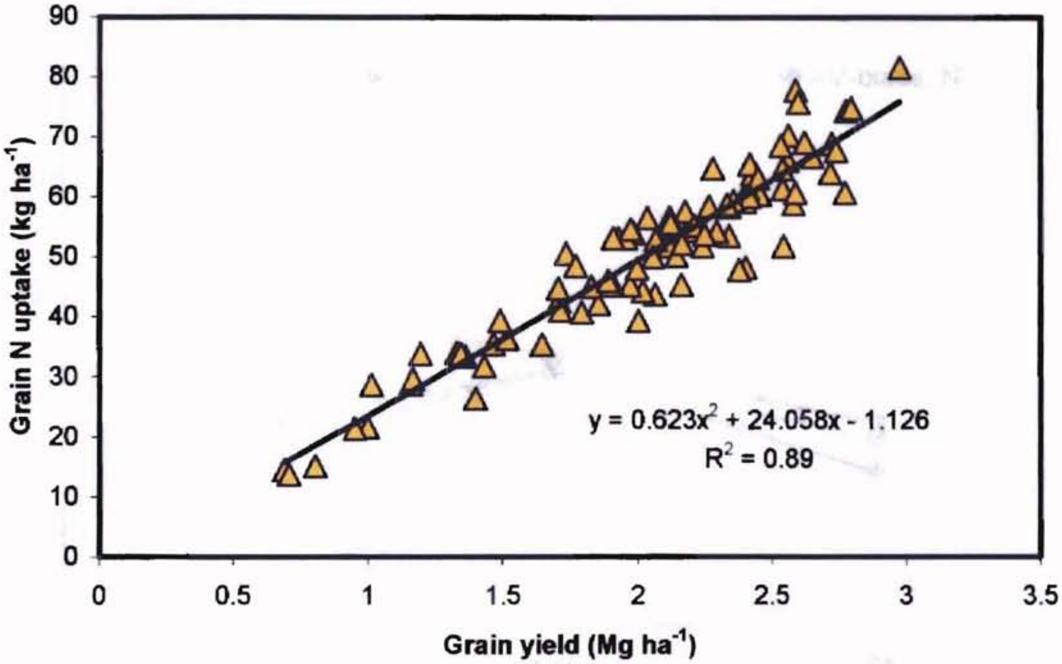

Figure 2. Relationship between grain yield and grain N uptake at Efaw and Lahoma, 2002.

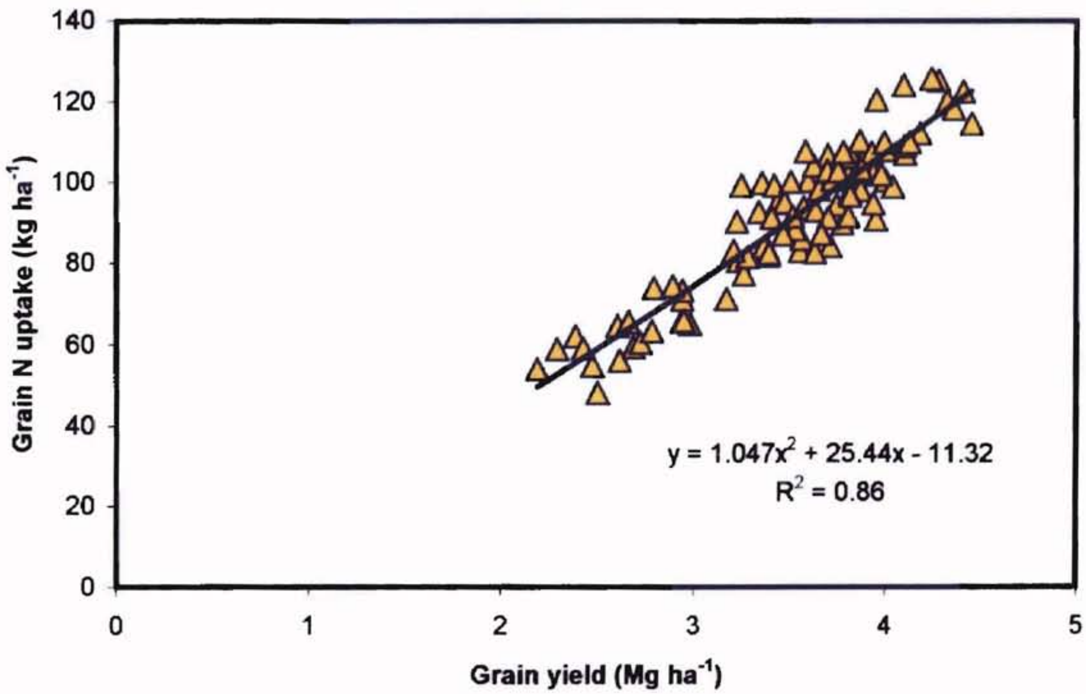

Figure 3. Effect of N rate, N method, and tillage on nitrogen use efficiency at Efaw, OK, 2001.

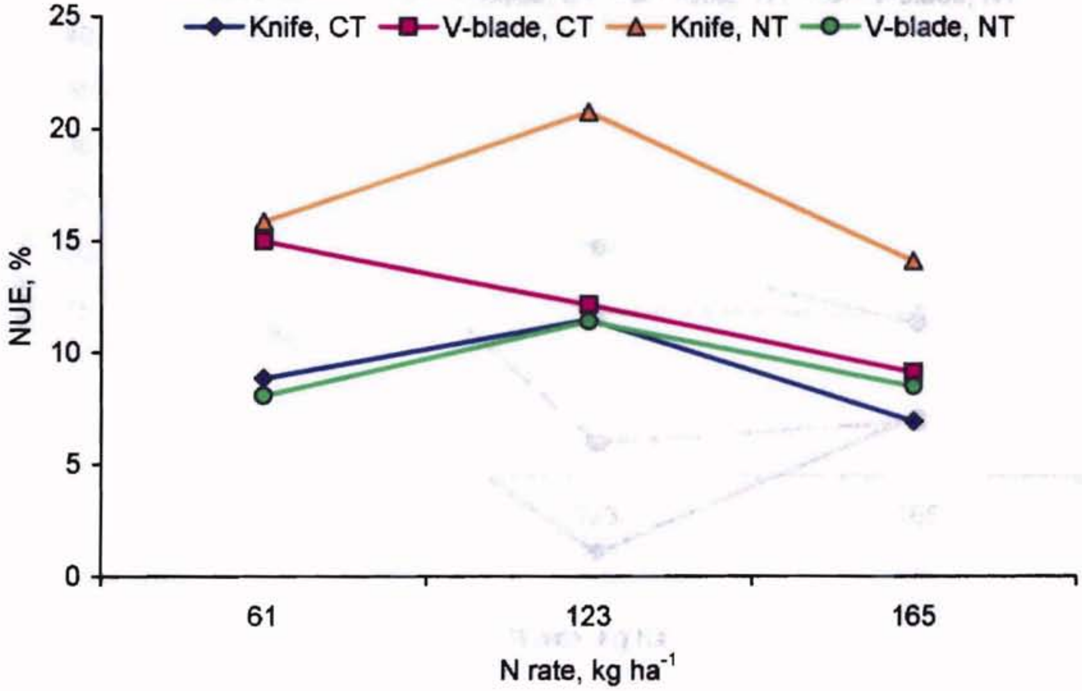

Figure 4. Effect of N rate, N method, and tillage on nitrogen use efficiency at Lahoma, OK, 2001.

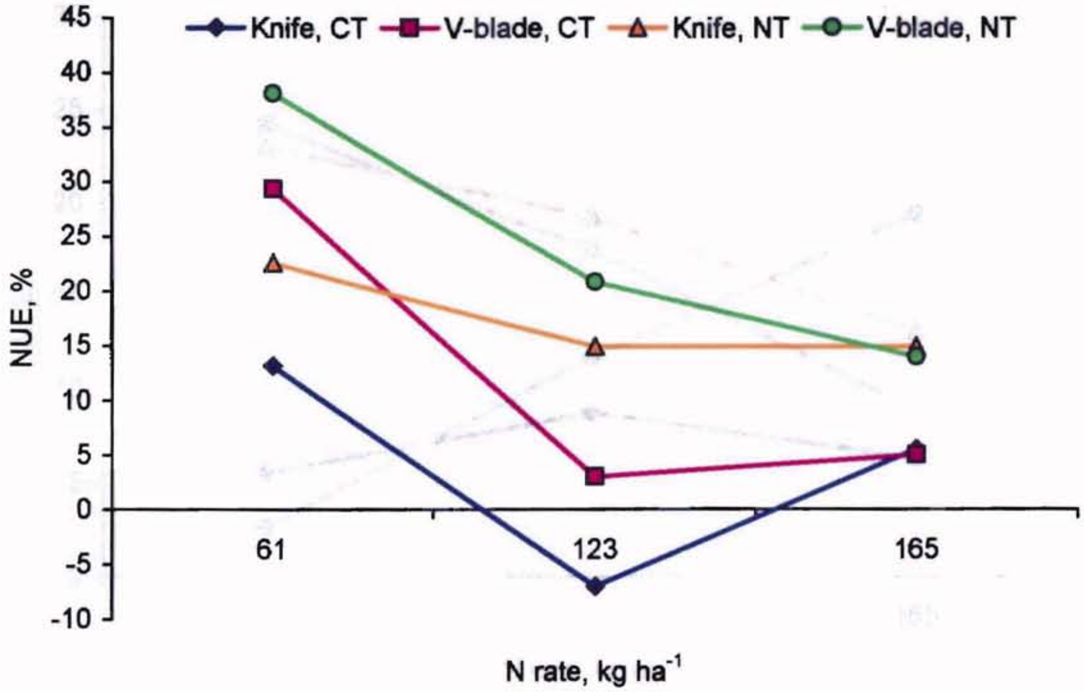

Figure 5. Effect of N rate, N method, and tillage on nitrogen use efficiency at Efaw, OK, 2002.

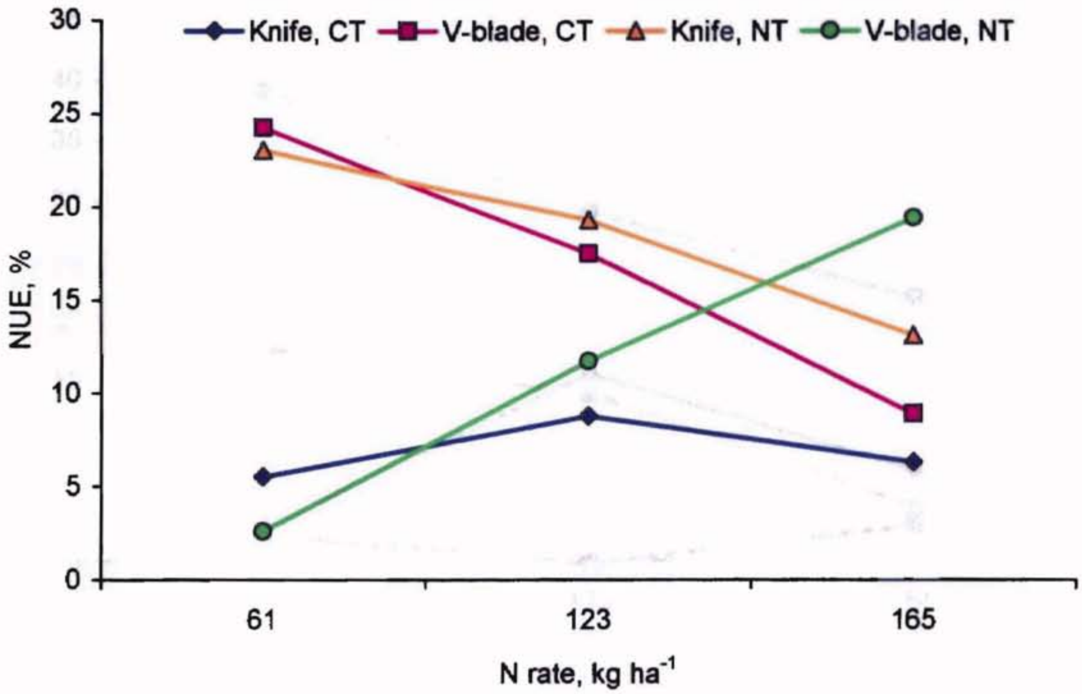

Figure 6. Effect of N rate, N method, and tillage on nitrogen use efficiency at Lahoma, OK, 2002.

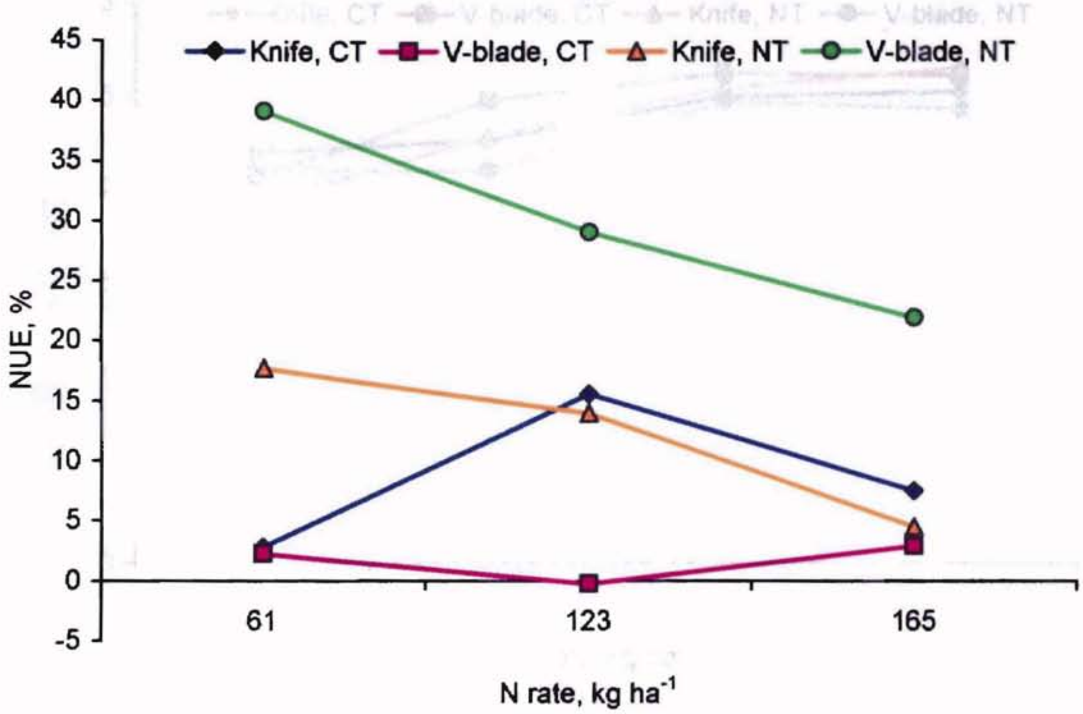

Figure 7. Effect of N rate, N method, and tillage on grain yield at Efaw, OK, 2001.

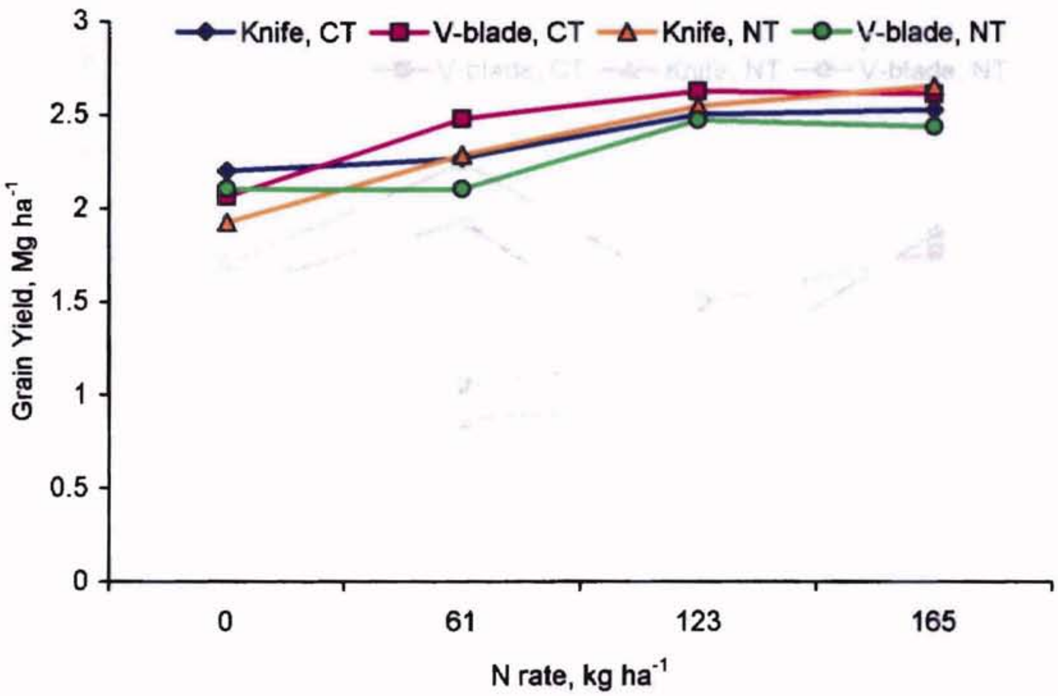

Figure 8. Effect of N rate, N method, and tillage on grain yield at Lahoma, OK, 2001.

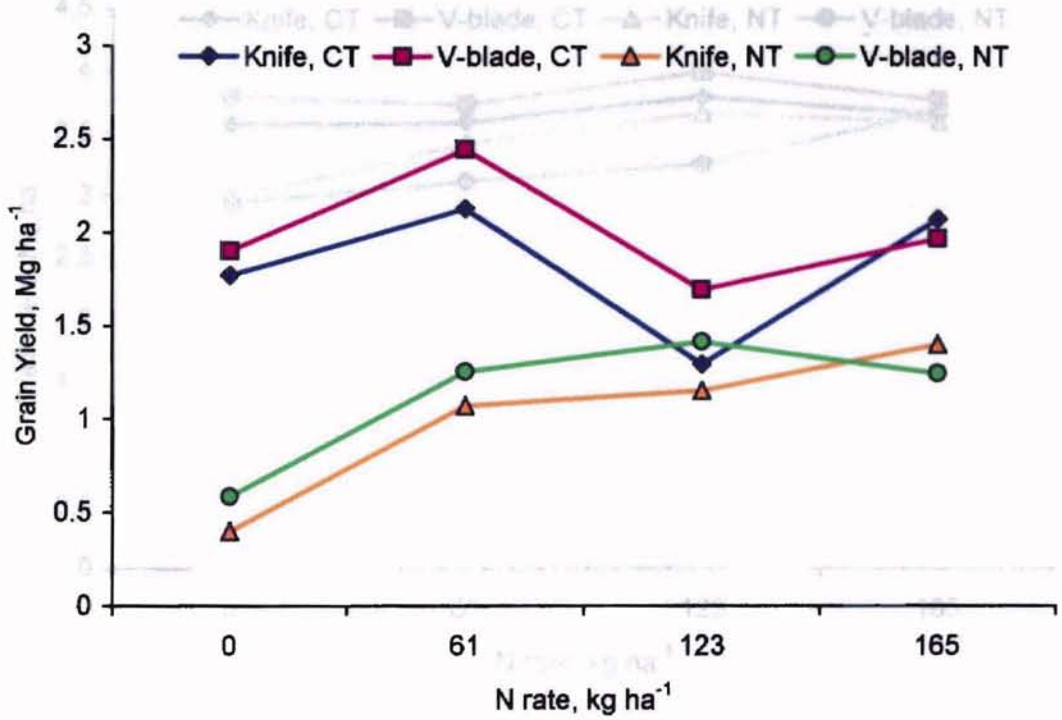

Figure 9. Effect of N rate, N method, and tillage on grain yield at Efaw, OK, 2002.

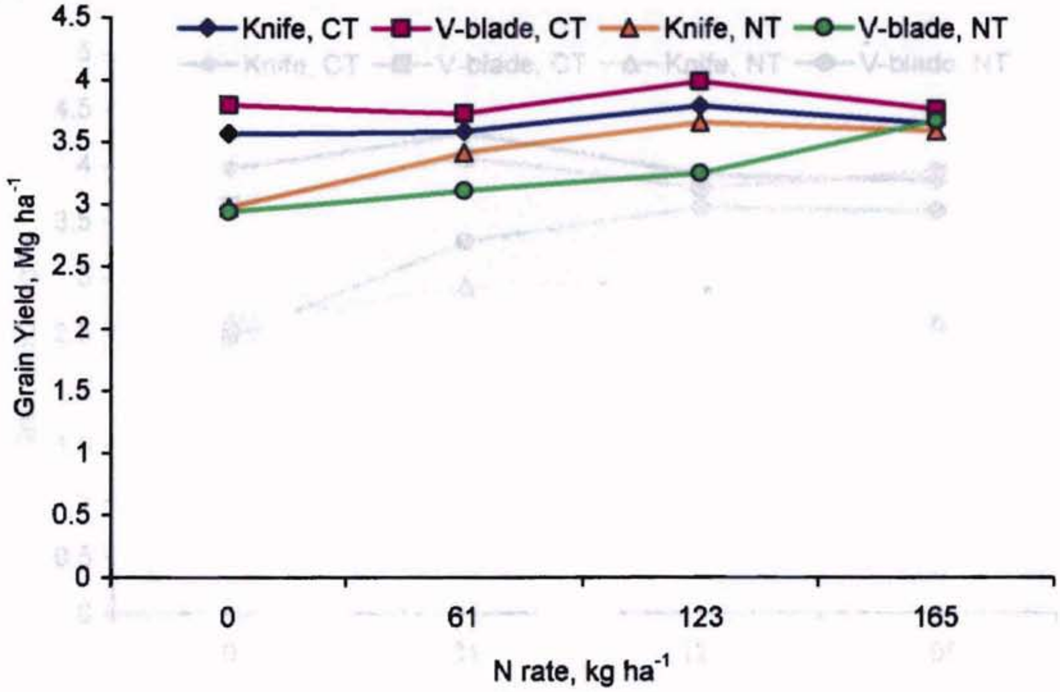

Figure 10. Effect of N rate, N method, and tillage on grain yield at Lahoma, OK, 2002.

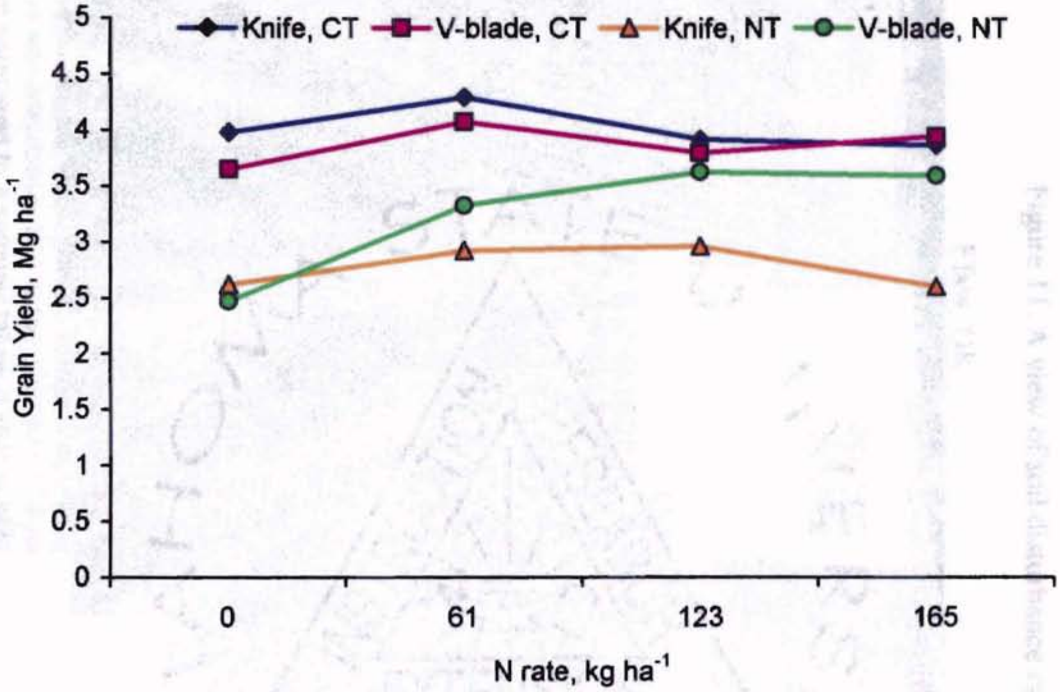

Figure 11. A view of soil disturbance caused by AA V-blade application in no-till at 2002.

Efaw, OK

*Note less soil disturbance due to the utilization of a summer cover crop when compared to a summer fallow (Lahoma site).

Lahoma, OK

*Note the knife application on the left and the V-blade application on the right of this photograph.

Figure 12. A view of emergence and seedbed differences caused by AA application in no-till at Lahoma, OK, 2002.

*V-blade application in center with a knife application on the right.

VITA 2

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Thesis: EFFECT OF TILLAGE AND ANHYDROUS AMMONIA APPLICATION ON NITROGEN USE EFFICIENCY OF HARD RED WINTER WHEAT

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