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Spring Wheat Response to Tillage System and Nitrogen Fertilization within a Crop–Fallow System

Ardell D. Halvorson,* Alfred L. Black, Joseph M. Krupinsky, Steven D. Merrill, Brian J. Wienhold, and Donald L. Tanaka

ABSTRACT

Spring wheat (*Triticum aestivum* L.) production in the northern Great Plains generally utilizes conventional tillage systems. A 12-yr study evaluated the effects of tillage system [conventional-till (CT), minimum-till (MT), and no-till (NT)], N fertilizer rate (0, 22, and 45 kg N ha^{-1}), and cultivar (Butte86 and Stoa) on spring wheat grain yields in a dryland spring wheat–fallow rotation (SW–F). Butte86 yields with CT exceeded NT yields in five out of 12 years with 0 and 22 kg N ha^{-1} applied, and four years with 45 kg N ha^{-1} applied. Stoa yields with CT exceeded NT yields in three out of 12 years with no N applied, four years with 22 kg N ha^{-1} applied, and only one year with 45 kg N ha^{-1} applied. Yields with NT exceeded those with CT in one year. Most years, yields with MT equaled those with CT. Responses to N tended to be greatest in years when spring soil NO_3–N was lowest. Positive yield responses to N fertilization with CT occurred in three years with Butte86 and two years with Stoa; with MT, four years with Butte86 and two years with Stoa; and with NT, five years with Butte86 and three years with Stoa. Cultivars were not consistent in their response to tillage and N fertilization. These results indicate that farmers in the northern Great Plains can successfully produce spring wheat in a SW–F system using MT and NT systems, but yields may be slightly reduced when compared with CT systems some years.

In the semi-arid Great Plains, plant-available water (PAW) and soil erosion are major factors limiting agricultural production (Deibert et al., 1986; Stewart, 1990). Therefore, farmers need to manage crop residues and tillage to control soil erosion and effectively store and use the limited precipitation received for crop production (Black and Power, 1965; Merrill et al., 1995; Tanaka, 1985, 1989). The NT and MT systems are an effective step in efficiently saving more precipitation for crop production (Aase and Schaefer, 1996; Black and Bauer, 1990; Peterson et al., 1996; Tanaka, 1985; Tanaka and Anderson, 1997).

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Tanaka (1989) reported more soil water storage and surface residue cover with chemical fallow than with stubble mulch fallow in northeast Montana. The additional soil water, however, did not always result in increased spring wheat yields. Black and Power (1965) reported similar responses, but felt that the herbicides available at that time for use in chemical fallow may have reduced spring wheat yields in some years. Norwood et al. (1990) reported yearly variations in winter wheat–fallow yields between tillage systems in the central Great Plains due to climate variability.

The traditional crop–fallow system of farming using CT has used water (precipitation) inefficiently, as evidenced by the development of dryland saline-seeps in the northern Great Plains (Halvorson and Black, 1974). Use of MT and NT systems may enhance saline-seep development when using a crop–fallow system of farming (Halvorson, 1990). Deibert et al. (1986) suggested that farmers in the northern Great Plains need to reduce or eliminate the 20- to 21-mo fallow period from their production systems to attain more efficient use of limited water supplies. Improved levels of soil fertility have been shown to increase water-use efficiency of crop–fallow systems by increasing crop yields (Black et al., 1981; Onken et al., 1990). Hall and Cholick (1989) reported varying responses of spring wheat cultivars to tillage system and a need to select cultivars for use under NT conditions. Because previous research tended to address either tillage system or fertility level alone, we conducted this study to determine the effects of tillage system, N fertilization rate, and cultivar on spring wheat grain yields in a dryland SW–F system.

METHODS AND MATERIALS

The study was initiated in 1984 on a Temvik–Wilton silt loam soil (fine-silty, mixed, superactive frigid Typic and Pachic Haplustolls) located near Mandan, ND. Surface soil pH was 6.4, soil organic carbon was 21.4 g kg^{-1}, and soil test P was 20 to 26 mg kg^{-1} in the spring of 1984 (Black and Tanaka,

Abbreviations: CT, conventional-till; MT, minimum-till; NT, no-till; PAW, plant-available water; TPAW, total plant-available water; SW–F, spring wheat–fallow rotation.

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Table 1. Number of tillage operations and burn-down herbicide applications made during the non-crop fallow period prior to each spring wheat crop for the conventional-till (CT), minimum-till (MT), and no-till (NT) treatments.

	CT					MT				NT	
	Tillage operations			Herbicide applications		Tillage operations		Herbicide applications		Herbicide applications	
Year	Disk	Sweep plow	Other	Glyphosate†	Glyphosate + 2,4-D†	Sweep plow	Other	Glyphosate	Glyphosate + 2,4-D	Glyphosate	Glyphosate + 2,4-D
1985	1	3			1	2			2		3
1986	1	3			1	2			2		3
1987	1	3			1	1			3		4
1988	1	3			1	2			2		3
1989	2	1		2		2		2		3	
1990	2	1		2		2		3		2	1
1991	2				2	2			3		4
1992		2		1		1		1	1	2	2
1993	1	1		3		1		4		4	
1994	2	1			1	1	M‡		1		2
1995	1	3	H‡			2	M	2		3	
1996	1	2	M			2		1		4	

† Glyphosate = Isopropylamine salt of N-(phosphonomethyl)glycine; 2,4-D = 2,4-dichlorophenoxyacetic acid.
‡ H = Heavy duty long–tine harrow; M = John Deere Mulch Master (John Deere, Moline, IL). Trade names and company names are included for the benefit of the reader and do not imply any endorsement or preferential treatment of the product by the USDA-ARS.

1997). Data collection was from 1985 through 1996. Spring wheat was produced in a crop–fallow system under three tillage systems, CT, MT, and NT. Nitrogen fertilizer was applied in early spring each crop year as a broadcast application of NH_4NO_3 at rates of 0, 22, and 45 kg N ha^{-1}. Exceptions were 1991 and 1992, when no N was applied because of a build-up of residual soil NO_3–N due to drought conditions and low yields in 1988 and 1989. Phosphorus fertilizer was applied broadcast at a rate of 40 kg P ha^{-1} at the beginning of the study in October 1983. Soil test P levels in the 0- to 15-cm depth averaged 16 mg kg^{-1} in 1991 and 13 mg kg^{-1} in 1996. Two spring wheat cultivars, Butte86 and Stoa, were used throughout the study. The cultivars had good yield potential but slightly different maturity dates. Each main block of the study was 137.2 by 73.1 m in size. Tillage plots (45.7 × 73.1 m) were oriented in a north-south direction, N plots (137.2 × 24.4 m) in an east-west direction across all tillage plots, and cultivars (22.9 × 73.1 m) in a north-south direction within tillage plots and across all N plots. The smallest plot, with the combination of all variables, was 22.9 by 24.4 m. Duplicate sets of plots were established to allow all phases of the crop–fallow system to be present each year. Experimental design was a strip-strip-split plot with tillage and N rate treatments stripped and cultivar as subplots with 3 replications.

The fallow period began in August or September each year following spring wheat harvest and continued until spring wheat planting in May, 20- to 21-mo later. The CT treatments were generally not tilled in the fall following spring wheat harvest. Tillage operations (Table 1) for the fallow period generally began the following spring and summer, with one shallow (<8 cm) tillage operation with a sweep plow being performed just prior to spring wheat planting. Surface residue cover at planting was generally <30%. A burn-down herbicide was generally applied in mid- to late-July during the summer of fallow. Besides eliminating weeds, the operation also helped to maintain surface residue cover in the CT treatment by reducing the number of tillage operations. All tandem disk operations were performed at a depth of 8 to 12 cm. The MT treatments were generally not tilled in the fall following spring wheat harvest, but were tilled once with a sweep plow the following spring. Burn-down herbicide was applied as needed throughout the fallow period. One sweep plow operation was performed just prior to spring wheat planting, with 30 to 60% residue cover at planting. All sweep plow operations were performed at a shallow depth (<8 cm). The NT treatments were not tilled, but received burn-down herbicide applications as needed to control weed growth during the fallow period (Table 1), with generally >60% surface residue cover at planting. Residue cover estimates were visual observations based on experience with photographic measurements made of residue cover in these SW–F plots (Merrill et al., 1995). Spring-applied herbicides were used to control broadleaf and grassy weed species within the growing spring wheat crop. Weed control was uniform across all plots and excellent in most years.

The spring wheat was usually planted in early May at a seeding rate of about 3.2 million seeds ha^{-1} using a NT disk drill with 17.8-cm row spacing. For grain yield determination, the plots were harvested in mid- to late-August each year by hand cutting spring wheat samples from two 1.5 m^2 areas within each plot (1985–1993). In 1994 through 1996, grain yields were determined from a 50 m^2 area with a plot combine. Grain yields are expressed on a 120 g kg^{-1} water content basis.

Soil samples (one 3-cm diameter core per plot) were collected for gravimetric soil water and NO_3–N analyses from one cultivar plot for each tillage and N fertilizer treatment. The samples were collected each spring (April) before N fertilization. Samples were collected in 30-cm increments to a depth of 120 cm. Soil NO_3–N was determined by autoanalyzer (Lachat Instruments QuikChem Method 12-107-04-1-B, Lachat Instruments, Milwaukee, WI; Technicon Industrial Systems Industrial Method 100-70W, Technicon Industrial Systems, Tarrytown, NY) on a 5:1 extract/soil ratio. A 2 *M* KCL extracting solution was used from 1985 through 1993 and a 0.01 *M* $CaSO_4$ extracting solution was used from 1993 through 1996. Volumetric soil water content was estimated from gravimetric soil water measurements using a soil bulk density of 1.42 gm cm^{-3} for the profile (Black and Tanaka, 1997). Total plant-available water (TPAW) was estimated as the sum of spring soil PAW in the 0- to 120-cm profile plus growing season (April through August) precipitation. Spring soil PAW was estimated by subtracting the lowest measured soil water content (152 mm) in the 0- to 120-cm profile following spring wheat harvest during the 12-year study from soil water contents in the 0- to 120-cm soil profile each spring, similar to the lower limit method described by Ratliff et al. (1983) and Ritchie (1981). Precipitation was measured with a recording rain gauge at the site from April through October each year. November through March precipitation was estimated from the U.S. Weather Bureau measurements made at the Northern Great Plains Research Laboratory at Mandan, ND, located approximately 5 km northeast of the site.

Analysis of variance procedures were conducted using SAS

statistical (ANOVA) procedures (SAS Institute, 1991) with years treated as a fixed variable. All differences discussed are significant at the $P = 0.05$ probability level unless otherwise stated. An LSD was calculated only when the analysis of variance F-test was significant at the $P = 0.05$ probability level.

RESULTS AND DISCUSSION

Precipitation and Plant-Available Water

Annual precipitation (Fig. 1) during the 12-yr period from 1985 through 1996 varied from a low of 206 mm in 1988 to a high of 655 mm in 1993. The average annual precipitation during the study at the research site was 422 mm, which was 13 mm more than the 82-year average at the Northern Great Plains Research Laboratory. Similar trends were observed for the April through August growing season precipitation, with a low of 132 mm in 1988 and a high of 602 mm in 1993, a site average of 296 mm, and an 82-yr average of 287 mm. Three consecutive years, 1988 to 1990, provided an opportunity to obtain information on the effects of drought on spring wheat production in a crop–fallow system. Total plant-available water was below 370 mm these three years (Fig. 1). Annual growing season precipitation in 1986, 1993, and 1995 was above average (Fig. 1). Total plant-available water also was considerably above the average (485 mm) during these years with TPAW levels of 603, 841, and 689 mm for 1986, 1993, and 1995, respectively. Tillage system had no effect on the level of spring PAW in this SW–F system, with PAW levels of 179, 180, and 184 mm for CT, MT, and NT treatments, respectively. Total plant-available water varied only with year (Fig. 1). The fact that no differences in PAW or TPAW were found among tillage treatments should probably be expected, since the 20 to 21 mo of fallow prior to planting the spring wheat crop allowed for recharge of the rootzone soil water most years. This observation is consistent with that of Pannkuk et al. (1997), who found that in the Pacific Northwest the fallow period tillage system had little effect on soil profile water at planting. In addition, soil water measurements were made in early spring, immediately following spring thaw, and before any spring preplant tillage operations were performed to influence soil water loss. Cold soil temperatures also reduced evaporation loss from the soil surface.

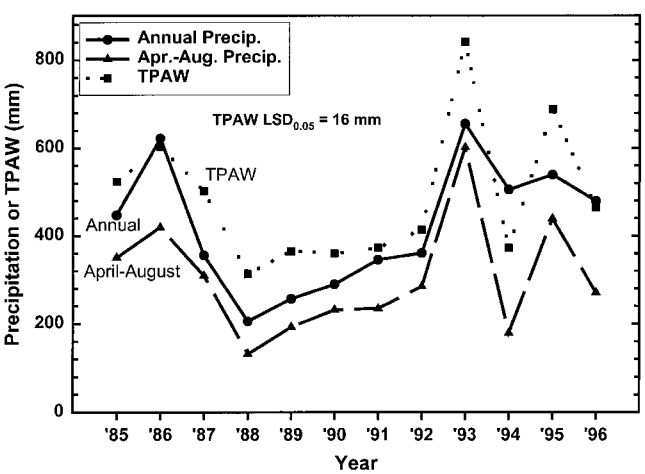

Fig. 1. Annual and growing season (April through August) precipitation and total plant-available water (TPAW) for each year at the study site.

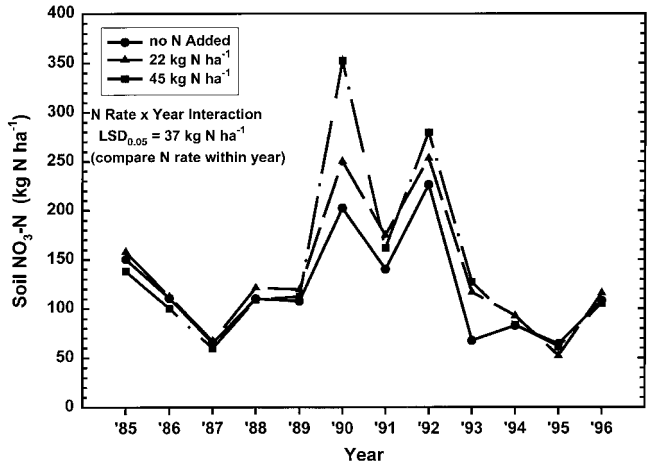

Fig. 2. Spring soil NO_3–N in the 0- to 120-cm soil profile as a function of years for N rate treatments.

Soil NO_3–N

Spring soil NO_3–N levels varied with N rate ($P = 0.03$) and year ($P = 0.001$) with a significant N rate × year ($P = 0.0001$) interaction. Spring soil NO_3–N levels were similar for all N rates from 1985 through 1989 (Fig. 2). In 1990 and 1992, soil NO_3–N levels increased, with the greatest level of spring soil NO_3–N associated with the 45 kg ha^{-1} N rate. Soil NO_3–N levels declined in 1993, 1994, and 1995 for all N rates, with no difference in spring soil NO_3–N among N rates in 1996. No N fertilization in 1991 and 1992 along with fair to good spring wheat yields probably contributed to this decline in spring soil NO_3–N levels. All spring soil NO_3–N levels had declined below 1985 levels by 1996. Average spring soil NO_3–N (0- to 120-cm depth) levels in the CT, MT, and NT plots were 144, 136, and 117 kg N ha^{-1}, respectively.

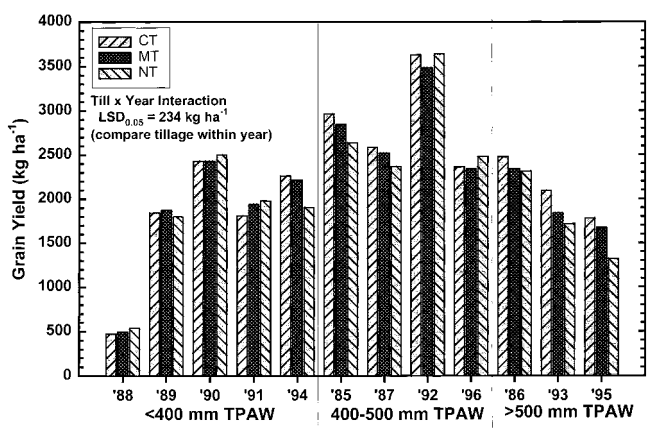

Fig. 3. Grain yield as a function of years, grouped by level of total plant-available water (TPAW), for conventional-till (CT), minimum-till (MT), and no-till (NT) treatments.

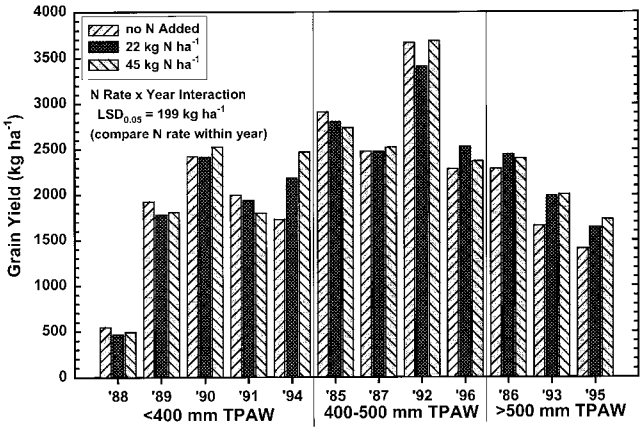

Fig. 4. Grain yield as a function of years, grouped by level of total plant-available water (TPAW), for N rate treatments.

Grain Yields

Spring wheat grain yields were significantly affected by tillage system ($P = 0.0001$), N fertilization rate ($P = 0.01$), and years ($P = 0.0001$). However, significant tillage × year ($P = 0.028$), N rate × year ($P = 0.0001$), and tillage × N rate × cultivar × year ($P = 0.002$) interactions for grain yield were present. The yearly yield data were grouped by level of TPAW (<400 mm, 400–500 mm, and >500mm) in Fig. 3 and 4 to show the relationship of TPAW on spring wheat yields.

Tillage × N Rate × Cultivar × Year Interaction

Grain yields for the tillage × N rate × cultivar × year interaction are shown in Table 2. Examination of the yield data in Table 2 reveals that there are no consistent trends in the yield data with regards to tillage, N rate, or cultivars over years. There were several factors that probably contributed to the four-way interaction. The presence of a high level of available soil NO_3–N in all plots was sufficient to produce more grain yield than was attained in this study. Visually, vegetative growth appeared to be stimulated by N application most years, which tended to depress grain yields in drier years and increase grain yields in some of the wetter years. This observation is supported by harvest index and straw yield data not reported here. Excessive vegetative growth increased disease effects in some years, especially the wet years. Stoa heads and matures later than Butte86, which enhances its susceptibility to climate and disease interactions. The following discussion describes the spring wheat yield responses to the tillage, N, and cultivar treatments within years.

Tillage Effects on Yield

By comparing tillage effects on spring wheat grain yields (Table 2) within N rate × cultivar × year, one finds that at the zero N rate, Butte86 yields with CT were greater than those with NT in 1985, 1986, 1987, 1993, and 1995. Stoa CT yields were greater than those with NT in 1985, 1993, and 1995. At the zero N rate, MT yields for Butte86 exceeded those with NT in 1985 and 1995; for Stoa, MT yields exceeded those with NT in 1993 and 1995. In 1992, Stoa yields with NT exceeded those with CT and MT at the zero N rate. With the application of 22 kg N ha^{-1}, Butte86 yields with CT

Table 2. Spring wheat grain yields for the significant tillage × N rate × cultivar × year interaction.†

	Nitrogen (N) fertilization rate								
	0 kg N ha^{-1}			22 kg N ha^{-1}			45 kg N ha^{-1}		
Year	CT‡	MT‡	NT‡	CT	MT	NT	CT	MT	NT
					Butte 86				
1985	3055	3033	2581	3062	2789	2482	2784	2813	2615
1986	2772	2090	2344	2548	2419	2512	2694	2383	2390
1987	2560	2434	2273	2734	2378	2448	2578	2528	2341
1988	522	507	542	333	411	521	425	366	515
1989	1904	1997	1727	1872	1684	1736	1895	1937	1769
1990	2259	2424	2307	2398	2254	2471	2439	2577	2595
1991	1910	2070	2027	1875	1990	1963	1657	1990	1881
1992	3746	3518	3830	3494	3626	3366	4180	3585	3877
1993	2370	1546	1343	2417	2019	1849	2211	2020	2007
1994	1889	1702	1648	2438	2332	1850	2617	2531	2334
1995	1900	1916	769	2143	1888	1500	2182	1647	1695
1996	2476	2255	2243	2724	2675	2637	2244	2579	2735
					Stoa				
1985	3108	2966	2725	2900	2902	2684	2887	2569	2750
1986	2264	2218	2039	2413	2326	2460	2166	2612	2149
1987	2569	2645	2392	2552	2415	2322	2532	2727	2436
1988	539	573	606	485	541	506	523	570	542
1989	1944	2038	1949	1718	1802	1862	1725	1772	1738
1990	2527	2349	2653	2309	2664	2403	2647	2312	2588
1991	1878	2016	2082	1910	1829	2065	1632	1751	1864
1992	3394	3532	3976	3569	3110	3279	3405	3541	3523
1993	1521	1727	1452	2112	1814	1716	1942	1920	1937
1994	1701	1850	1587	2388	2349	1740	2543	2518	2275
1995	1444	1417	1003	1428	1526	1359	1598	1654	1600
1996	2245	2121	2379	2333	2364	2439	2161	2054	2449

† Interaction $LSD_{0.05}$ = 272 kg ha^{-1} (compare tillage within N rate × cultivar × year); Interaction $LSD_{0.05}$ = 274 kg ha^{-1} (compare N rates within tillage × cultivar × year).

‡ CT = conventional-till; MT = minimum-till; and NT = no till.

exceeded those with NT in 1985, 1987, 1993, 1994, and 1995. Butte86 yields with MT exceeded those with NT in 1985, 1994, and 1995. Butte86 yields with CT exceeded those with MT in 1985, 1987, and 1993. With the application of 22 kg N ha^{-1}, Stoa yields with CT exceeded those with NT in 1985, 1992, 1993, and 1994. Stoa yields with MT exceeded those of NT in 1985 and 1994. Stoa yields with CT exceeded those with MT in 1992 and 1993. With the application of 45 kg N ha^{-1}, Butte86 yields with CT exceeded those with NT in 1986, 1992, 1994, and 1995. In 1996, Butte86 yields with NT and MT exceeded those with CT at the 45 kg ha^{-1} N rate. Butte86 yields with MT exceeded those with CT in 1991 and 1996 and those with NT in 1994 and 1996. Stoa yields with CT at the 45 kg ha^{-1} N rate exceeded those with NT in 1987, and NT yields exceeded those of CT and MT in 1996. Stoa yields with MT exceeded those with CT in 1986 and those with NT in 1986 and 1987.

Nitrogen Effects on Yield

Comparing N effects on spring wheat grain yield (Table 2) within tillage × cultivar × year, one finds that with CT, Butte86 yields were increased in 1992, 1994, and 1995 and decreased in 1985 and 1996 with the application of 45 kg N ha^{-1} when compared with yields with no N applied. Application of 22 kg N ha^{-1} increased Butte86 yields with CT in 1994 and 1995 above those with no N applied. With CT, Stoa yields were increased with application of 22 and 45 kg N ha^{-1} when compared with yields with no N applied in 1993 and 1994. Application of 45 kg N ha^{-1} decreased Stoa yields with CT in 1991 when compared with the 22 kg N ha^{-1} rate. With MT, N fertilization increased Butte86 yields in 1986, 1993, 1994, and 1996 above those yields with no N applied. Application of 45 kg N ha^{-1} did not result in greater yields in these years than with 22 kg N ha^{-1} applied. Stoa yields with MT were decreased in 1985 and increased in 1986 and 1994 by the application of 45 kg N ha^{-1} when compared with yields with no N applied. Application of 22 kg N ha^{-1} increased Stoa yields with MT above those with no N applied in 1990 and 1994. With NT, application of 45 kg N ha^{-1} increased Butte86 yields in 1990, 1993, 1994, 1995, and 1996 when compared with yields with no N applied. Application of 22 kg N ha^{-1} increased Butte86 yields with NT in 1993, 1995, and 1996 when compared with yields with no N applied. Stoa yields with NT were increased with application of 45 kg N ha^{-1} in 1993, 1994, and 1995 when compared with yields with no N applied, but decreased yields in 1992 when residual soil NO_3–N levels were high. Stoa yields with application of 22 kg N ha^{-1} with NT were only increased in 1986 and 1995 when compared with yields with no N applied.

Cultivar and Year Effects on Yield

Cultivar response to tillage and N varied from year to year, with Butte86 tending to have slightly greater yields than Stoa in most years. Butte86 responded more frequently to N application than did Stoa in this SW–F system. Grain yields were severely depressed in 1988 compared with other years due to very low amounts of growing season precipitation (Fig. 1). Grain yields in 1989 were not depressed as much in this SW–F system as they were in the adjacent annual cropping system (Halvorson et al., 1999a, 1999b, and 2000), which did not have an extended fallow period between crops. The till × N rate × cultivar × year interaction resulted because of the variation in spring wheat response to treatment from year to year. An extended fallow period prior to crop planting tends to mask yearly treatment responses to tillage, N fertilization, or cultivar, similar to observations made by Pannkuk et al. (1997) in the Pacific Northwest.

Tillage × Year Interaction

The grain yield tillage × year interaction is shown in Fig. 3. During the five years with <400 mm of TPAW, tillage system did not significantly affect grain yields, except for 1994 when yields were CT = MT > NT. Grain yields were lowest for 1988, when precipitation and TPAW (Fig. 1) were low. In 1989 and 1990, grain yields in this SW–F system were not affected as much by the drought conditions as the grain yields in the annual cropping system (Halvorson et al. 1999a, 1999b, 2000). During the years with 400 to 500 mm TPAW, yield responses to tillage system were only significant in 1985, when grain yields with CT were greater than those with NT. During years of >500 mm TPAW, tillage system affected grain yields in 1993 (CT > MT = NT) and 1995 (CT = MT > NT). Grain yields in the >500 mm TPAW group did not increase above those within the 400 to 500 mm TPAW group, as one may expect. This indicates that water was not the limiting factor in the >500 mm TPAW group. One reason for grain yields not increasing above those within the 400 to 500 mm TPAW group would be an increase in leaf spot disease severity associated with higher moisture levels (Krupinsky et al., 1997, 1998).

N Rate × Year Interaction

The N rate × year interaction effects on grain yield are shown in Fig. 4. During the years of <400 mm TPAW, a negative response to N application was observed in 1991, with similar trends in 1988 and 1989. This negative yield response to N fertilization probably resulted because of the increased early vegetative growth observed with N application, which increased the transpirational demand, resulting in increased plant water stress during grain fill. Nielsen and Halvorson (1991) reported similar effects of N fertilization on winter wheat during years with limited TPAW. A positive response to N application was observed in 1994, when residual spring soil NO_3–N was lower at planting than in previous years. Grain yield responses to N fertilization during years with 400 to 500 mm of TPAW varied from year to year. In 1992, grain yields were less with 22 kg N ha^{-1} than for the other N treatments. In 1996, grain yields were increased with the application of 22 kg N ha^{-1}. During the years with >500 mm TPAW, grain

yields were optimized with 22 kg N ha^{-1} in 1993 and 1995. The lack of a consistent N response suggests that the soil was able to mineralize sufficient N during the 20- to 21-mo fallow period to meet spring wheat needs the following year. Response to N fertilization was greatest in 1993, 1994, and 1995 when spring residual N levels were <100 kg ha^{-1}.

When evaluating spring wheat plants for leaf spot diseases during another phase of this study, differences among N treatments (both cultivars) were significant for 10% of the disease ratings, compared with 45% of the ratings for spring wheat in the continuous cropping system (Halvorson et al., 2000). One can speculate that applied N had a lesser impact in the SW–F system because of the higher level of available soil N. This higher level resulted from N being mineralized from soil organic matter during the 20- to 21-mo fallow period. When differences were significant, higher levels of disease severity were associated with the zero N fertilizer treatment compared with the higher N treatments. The N × tillage interaction was significant for 21% of the ratings for disease severity. With no N added, leaf spot severity (data not reported) was higher with NT than with CT, but at higher N levels, the difference in leaf spot severity for the tillage treatments was greatly reduced or eliminated (Krupinsky et al., 1997, 1998). Nitrogen fertilization played an important role in maintaining a healthy spring wheat plant under NT conditions.

Main Effects

Grain yields by tillage systems were in the order of CT > MT > NT with respective yields of 2227, 2167, and 2101 kg ha^{-1}. Average grain yields were 2110, 2173, and 2212 kg ha^{-1} for the 0, 22, and 45 kg N ha^{-1} treatments, respectively. Average 12-yr grain yields for Butte86 (2203 kg ha^{-1}) were not different from those of Stoa (2126 kg ha^{-1}).

SUMMARY

The results of this study show that grain yields in this SW–F system were generally not enhanced using MT and NT systems when compared with CT. Butte86 yields with CT exceeded those with NT in five out of 12 years with the application of 0 and 22 kg N ha^{-1} and in four out of 12 years with the application of 45 kg N ha^{-1}. Stoa yields with CT exceeded those with NT in three out of 12 years without N fertilization, four out of 12 years with 22 kg N ha^{-1} applied, and one out of 12 years with 45 kg N ha^{-1} applied. Stoa yields with NT exceeded those with CT in one year at the 0 and 45 kg ha^{-1} N rates, and Butte86 yields in one year with 45 kg N ha^{-1}. Yields of both cultivars with MT exceeded those with NT in two out of 12 years at the 0 and 45 kg ha^{-1} N rates. Butte86 yields with 22 kg N ha^{-1} applied with MT exceeded those with NT in three out of 12 years, and Stoa yields in two out of 12 years. Except for one or two years, MT yields equaled those with CT when N fertilizer was applied.

Spring wheat response to N fertilization was not consistent from year to year, but yield response to N fertilization tended to be greatest in years when spring soil NO_3–N was lowest and precipitation was high. Nitrogen fertilization did help reduce the leaf disease pressure (Krupinsky et al., 1997, 1998) in years when leaf diseases were a problem. Butte86 yields with CT were increased by the application of 22 kg N ha^{-1} in two years and by the application of 45 kg N ha^{-1} in three years, and decreased by the application of 45 kg N ha^{-1} in two years. Stoa yields with CT were increased by N application in two out of 12 years and decreased in one year with the application of 45 kg N ha^{-1}. Butte86 yields with MT were increased in four out of 12 years with the application of N, and Stoa yields in two out of 12 years. Butte86 yields with NT were increased above those with no N applied in five out of 12 years with the application of 45 kg N ha^{-1} and in three out of 12 years with the application of 22 kg N ha^{-1}. Stoa yields with NT were increased above those with no N applied in two out of 12 years with the application of 22 kg N ha^{-1}, in three out of 12 years with 45 kg N ha^{-1} applied, and decreased in one year with the application of 45 kg N ha^{-1}.

These variations in yearly yield response to tillage and N treatments are in agreement with those observed by Tanaka (1989) in northeast Montana, Norwood et al. (1990) in western Kansas, and Pannkuk et al. (1997) in the Pacific Northwest for wheat–fallow systems. Spring soil water levels were similar for all tillage treatments at spring wheat planting each year. Spring wheat yields were abnormally low in only one year, 1988, which had the lowest level of precipitation and TPAW. Grain yields were maintained near normal in 1989 and 1990, despite the low level of growing season precipitation, in contrast to low spring wheat yields in the adjacent annual cropping system (Halvorson et al., 2000). This demonstrates the benefit of a fallow period preceding a crop during drought years. Spring soil NO_3–N levels increased following the drought years, possibly due to reduced crop N use in 1988 and 1989, but returned to 1985 levels by 1996 for all N rates. Spring soil N levels were greater than 100 kg N ha^{-1} in eight out of the 12 years for the zero N fertilizer rate. This was nearly adequate for the spring wheat yield levels attained in this study. These results indicate that farmers in the northern Great Plains can successfully produce spring wheat in a SW–F system using MT and NT systems, but yields may be slightly reduced in some years when compared with CT systems. Producers need to consider changing to more intensive cropping systems to reap the benefits of the MT and NT systems compared with CT in the northern Great Plains.

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