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Spring Wheat Response to Tillage and Nitrogen Fertilization in Rotation with Sunflower and Winter Wheat

Ardell D. Halvorson
USDA-ARS, adhalvor@lamar.colostate.edu

Alfred L. Black
USDA-ARS

Joseph M. Krupinsky
USDA-ARS

Steven D. Merrill
USDA-ARS

Brian J. Wienhold
University of Nebraska-Lincoln, Brian.Wienhold@ars.usda.gov

See next page for additional authors

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Authors

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SOIL MANAGEMENT

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ABSTRACT

Spring wheat (*Triticum aestivum* L.) is a major crop in the northern Great Plains that is generally grown following a 21-mo fallow period. A 12-yr study was conducted to determine the effects of tillage system [conventional-till (CT), minimum-till (MT), and no-till (NT)], N fertilizer rate (34, 67, and 101 kg N ha^{-1}), and cultivar (Butte86 and Stoa) on spring wheat yields within a dryland spring wheat (SW)–winter wheat (WW)–sunflower (*Helianthus annuus* L.) (SF) rotation. Grain yield responses varied with tillage system, N fertilizer rate, cultivar, and year as indicated by significant tillage × N rate × year and N rate × cultivar × year interactions. In years with >260 mm total plant available water (TPAW) but <400 mm TPAW, NT grain yields were greater than those with CT at the highest N rate, with similar trends at the medium and low N rates. When TPAW exceeded 400 mm, grain yields for CT were generally greater than for NT at the medium N rates. The greatest 12-yr average grain yield (1727 kg ha^{-1}) was obtained with NT and application of 101 kg N ha^{-1}. Grain yields were lowest during years when TPAW was <300 mm, with only small responses to tillage and N treatments. Cultivars responded similarly to N fertilization in years with >300 mm TPAW, with Butte86 yielding more than Stoa in 6 out of the 12 yr. Soil NO_3–N levels increased in the root zone following three consecutive drought years, but had declined to initial year levels by the end of the study. These results indicate that farmers in the northern Great Plains can produce SW following SF in annual cropping systems that do not include a fallow period, particularly if NT or MT systems are used with adequate N fertilization.

In the semi-arid northern Great Plains, plant-available water (PAW) and soil erosion are major factors limiting agricultural production. 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. No-till and minimum-till systems are effective steps in efficiently saving more precipitation for crop production (Aase and Schaefer, 1996; Halvorson, 1990b; Peterson et al., 1996; Tanaka and Anderson, 1997).

The traditional crop–fallow system of farming uses water/precipitation inefficiently as evidenced by the development of dryland saline-seeps in the northern Great Plains (Halvorson and Black, 1974). The solution to the saline-seep problem is to crop more intensively with efficient use of precipitation for crop production (Halvorson, 1990a). Saline-seep areas have been controlled and returned to crop production by growing alfalfa (*Medicago sativa* L.) and/or by annual cropping of the seep recharge area (Halvorson, 1984; Halvorson and Reule, 1980).

Deibert et al. (1986) suggested that farmers in the northern Great Plains need to use more continuous cropping and less crop–fallow to attain more efficient use of limited water supplies. Peterson et al. (1996) and McGee et al. (1997) point out that MT and NT fallow systems have a high percentage of the soil water in the profile recharged by the first spring following harvest. Continuing the fallow period for an additional 5 to 12 mo is very inefficient and costly. Therefore, cropping more intensively than crop–fallow is needed to efficiently use the water stored by NT and MT systems. Improved precipitation-storage efficiency with MT and NT allows producers the option of cropping more intensively than with crop–fallow (Halvorson and Reule, 1994; Peterson et al., 1996). Black et al. (1981) reported more efficient water use with more intensive cropping systems. Halvorson and Black (1985) reported crop yields that were generally >80% of 2-yr SW–fallow yields when grown in an annual cropping system with adequate N and P fertilization. Aase and Reitz (1989) and Aase and Schaefer (1996) reported that annually cropped SW with NT was more profitable and productive than SW–fallow in a 356 mm precipitation zone in northeast Montana.

Hall and Cholick (1989) reported varying responses of SW cultivars to tillage systems and a need to select cultivars for use under NT conditions. Most SW cultivars developed for use in the northern Great Plains have been developed using crop–fallow systems and low residue, CT environments.

Information is limited on the successes of more intensive dryland cropping systems in the northern Great Plains that include MT and NT management systems and a deep rooted crop, such as SF, in the rotation. In addition to more efficient water use, more intensive MT and NT cropping systems have the potential to be more profitable (Dhuyvetter et al., 1996) and reduce soil erosion potential (Merrill et al., 1999). This study was undertaken to determine the effects of tillage system (CT, MT, NT), N fertilizer rate (34, 67, and 101 kg N ha^{-1}),

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A.D. Halvorson, USDA-ARS, P.O. Box E, Fort Collins, CO 80522; A.L. Black, J.M. Krupinsky, S.D. Merrill, and D.L. Tanaka, USDA-ARS, P.O. Box 459, Mandan, ND; and B.J. Wienhold, USDA-ARS, 119 Keim Hall, East Campus, Univ. Nebraska, Lincoln, NE. Contribution from USDA-ARS. Received 26 May 1999. *Corresponding author (adhalvor@lamar.colostate.edu).

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Abbreviations: CT, conventional-till; MT, minimum-till; NT, no-till; PAW, plant-available water; SW, spring wheat; TPAW, total plant-available water; WW, winter wheat; SF, sunflower.

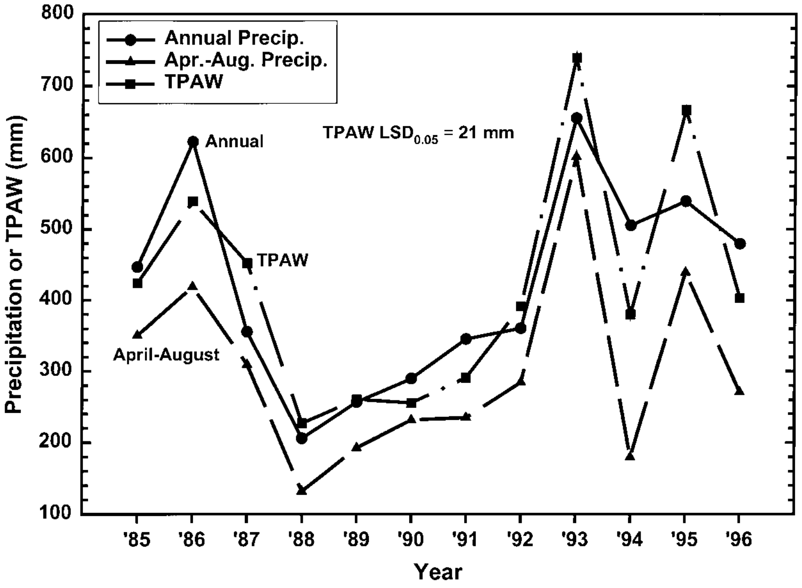

Fig. 1. Annual and growing season (April through August) precipitation and total plant available water (TPAW) for each year at the study site.

and cultivar (Butte86 and Stoa) on SW grain yields within a dryland SW–WW–SF rotation.

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, 1997). Data collection was from 1985 through 1996. An annual cropping rotation, SW–WW–SF, was managed under three tillage systems, CT, MT, and NT (Halvorson et al., 1999a, b). Nitrogen fertilizer was applied in early spring each year as a broadcast application of NH_4NO_3 at rates of 34, 67, and 101 kg N ha^{-1}, except for 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 from 1988 to 1990. 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 11 mg kg^{-1} in 1996. Two SW cultivars with good yield potential, Butte86 and Stoa, were used throughout the study. 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. Triplicate sets of plots were established to allow all phases of the rotation 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 CT treatments were generally not tilled in the fall after SF harvest but were disked once to a depth of 8 to 12 cm in the spring prior to SW planting. Surface residue cover was usually <30% after planting. Minimum-till treatments were generally not tilled in the fall after SF harvest but were undercut once in the spring with a sweep plow at a shallow depth (<7.5 cm) prior to SW planting. Surface residue cover was usually 30 to 60% after planting. No-till treatments were not tilled following SF harvest and received one application of glyphosate [N-(phosphonomethyl)glycine] herbicide just prior

Table 1. Spring soil NO_3-N levels (0- to 120-cm depth) for the tillage × N rate × year interaction.†

		Soil NO_3-N		
Year	N Rate	CT‡	MT	NT
		kg ha^{-1}		
1985	34	66	66	66
	67	61	61	61
	101	61	61	61
1986	34	47	49	45
	67	46	44	48
	101	66	41	52
1987	34	16	13	16
	67	22	20	19
	101	40	36	14
1988	34	14	15	15
	67	19	19	18
	101	14	27	24
1989	34	56	48	33
	67	132	44	54
	101	82	236	105
1990	34	77	69	19
	67	90	71	71
	101	243	215	137
1991	34	157	179	48
	67	319	220	145
	101	337	432	266
1992	34	204	173	49
	67	339	198	266
	101	400	412	188
1993	34	30	27	20
	67	144	57	16
	101	282	294	80
1994	34	108	201	59
	67	223	184	71
	101	398	140	73
1995	34	56	60	23
	67	51	109	42
	101	77	126	47
1996	34	29	29	28
	67	39	43	29
	101	52	57	40

† Interaction LSD$_{0.05}$ = 96 kg N ha^{-1} (compare tillage within N × year); LSD$_{0.05}$ = 97 kg N ha^{-1} (compare N rate within tillage × year).

‡ CT, conventional till; MT, minimum till; NT, no till.

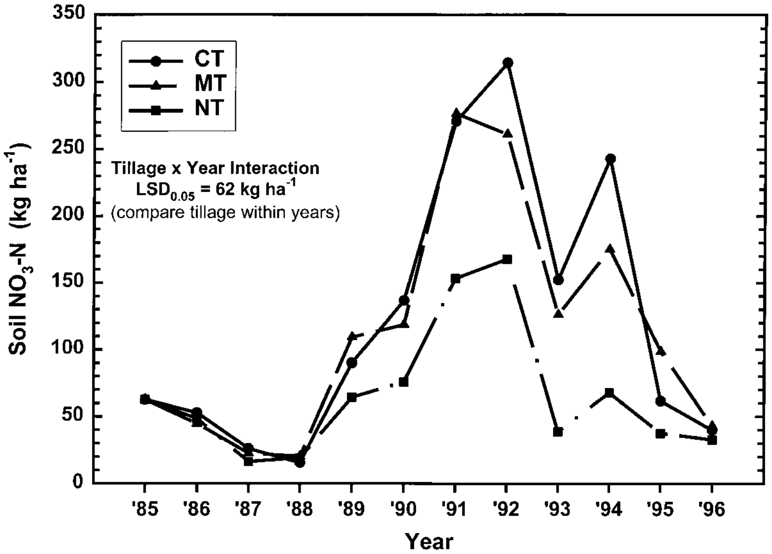

Fig. 2. Spring soil NO_3–N in 0- to 120-cm soil profile as a function of years for conventional-till (CT), minimum-till (MT), and no-till (NT) treatments.

to SW planting in 1985, 1986, 1989, 1990, 1993, and 1994. Surface residue cover was generally >60% after planting. No preplant herbicides were applied in the other years. Residue cover estimates were based on visual observations using experience with photographic measurements made of residue cover in adjacent SW–fallow plots (Merrill et al., 1995). Spring-applied herbicides were used to control broadleaf and grassy weed species within the growing SW crop. Tillage treatments, agronomic operations, and herbicides applied to the SF and WW crops are described by Halvorson et al. (1999a, 1999b).

The SW was generally planted in early May at a seeding rate of about 3.2-million seeds ha^{-1} with a NT disk drill with 17.8-cm row spacing. The plots were harvested in mid- to late-August each year by hand cutting SW samples for grain yield determination 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 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 for each depth increment by autoanalyzer (Lachat Instruments, 1989; Technicon Industrial Systems, 1973) on a 5:1 extract/soil ratio using 2 *M* KCl extracting solution (1985–1992) and a 0.01 *M* $CaSO_4$ extracting solution (1993–1996). 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 was estimated as the sum of spring soil PAW in the 0- to 120-cm profile plus growing season precipitation (April through August). Spring soil PAW was estimated by subtracting the lowest measured soil water content (152 mm) in the 0- to 120-cm profile following SW harvest during the 12-yr study from soil water contents in the 0- to 120-cm soil profile each spring. Precipitation was measured from April through October each year with a recording rain-gauge at the site. November through March precipitation was estimated from the U.S. Weather Bureau measurements made at the Northern Great Plains Research Laboratory at Mandan, ND, which was located approximately 5 km northeast of the site.

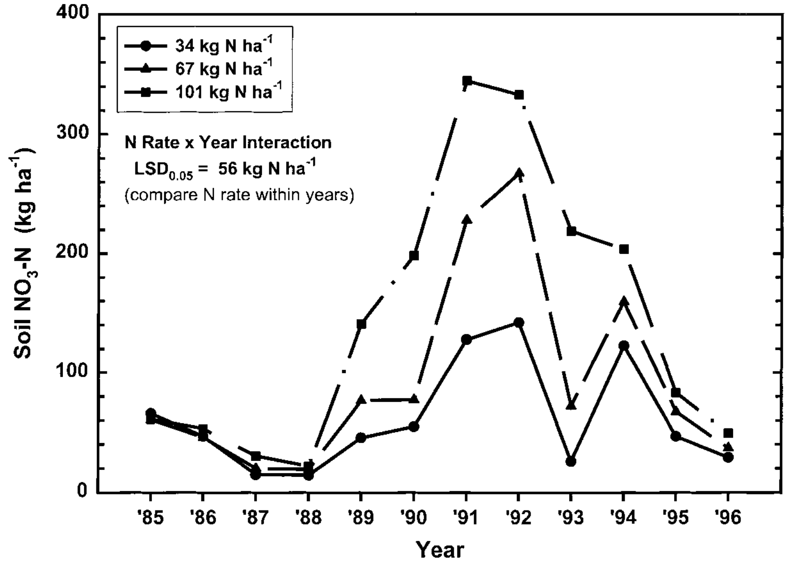

Fig. 3. Spring soil NO_3–N in 0- to 120-cm soil profile as a function of years for N rate treatments.

Analysis of variance procedures were conducted using SAS statistical 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. A least significant difference (LSD) was calculated only when the analysis of variance F-test was significant at the $P = 0.05$ probability level.

RESULTS

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, slightly more than the 409-mm 82-yr average at the Northern Great Plains Research Laboratory, Mandan, ND. 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 with a 12-yr site average of 296 mm, compared with an 82-yr average of 287 mm. Three consecutive years, 1988 through 1990, provided an opportunity to obtain information on the effects of drought on SW production following SF in rotation. Total plant-available water was below 260 mm these three years (Fig. 1), thus severe plant water stress reduced growth and grain yield potential (Major et al., 1988; Nielsen and Halvorson, 1991). Annual and growing season precipitation in 1986, 1993, and 1995 were above average (Fig. 1). Total plant available water (Fig. 1) also was considerably above the average (419 mm) during these years with TPAW levels of 539, 740, and 667 mm for 1986, 1993, and 1995, respectively. Tillage system affected the level of spring TPAW with 431, 418, and 408 mm of TPAW ($LSD_{0.05} = 8$ mm) for the NT, MT, and CT treatments, respectively.

Soil Nitrate Nitrogen

Spring soil NO_3–N levels varied significantly with tillage system, N rate, and year with significant tillage × year, N rate × year, and tillage × N rate × year interactions. Spring soil NO_3–N levels (0- to 120-cm depth) associated with the tillage × N rate × year interaction are reported in Table 1. No differences were observed in spring soil NO_3–N levels among tillage treatments when compared over N rates and years from 1985 through 1988. In 1989, spring soil NO_3–N levels were significantly greater with MT than with NT and CT for the highest N rate. In 1990, spring soil NO_3–N levels were greater with CT than NT at the highest N rate. In 1991, CT and MT had a higher level of soil NO_3–N than NT at the low N rate. At the medium N rate, CT had a higher soil NO_3–N level than MT and NT. At the high N rate, MT had a higher level of soil NO_3–N than CT and NT. In 1992, CT had a higher level of soil NO_3–N than MT and NT at the low and high N rates. At the medium N rate, soil NO_3–N was greater with CT than MT. In 1993, there were no differences in soil NO_3–N among tillage treatments at the low N rate, with CT having higher levels than NT at the medium N rate and CT and MT having higher levels than NT at the highest N rate. In 1994, MT had a higher level of soil NO_3–N than NT at the lowest N rate, with CT and MT having higher levels than NT at the medium N rate and CT having higher levels than MT and NT at the highest N rate. In 1995 and 1996, no differences were observed among tillage treatments for each of the N rates. The data in Table 1 show that spring soil NO_3–N in the soil profile had increased considerably following the drought years of 1988 through 1990, which experienced poor WW and SF yields and reduced N requirements (Halvorson et al., 1999a, b). The trend was for higher levels of soil NO_3–N with increasing N rates from 1990 through 1994, with spring soil NO_3–N levels in 1995 and 1996 approaching levels similar to those in 1985 at study initiation.

The tillage × year interaction also shows that spring soil NO_3–N levels increased within all tillage systems from 1989 through 1992 (Fig. 2) following the drought years (Fig. 1). The NT treatment had less soil profile

Table 2. Spring wheat grain yields for the tillage × N rate × year interaction† as grouped by level of total plant available water (TPAW).

Year	N Rate	Grain yield		
		CT‡	MT	NT
		kg ha^{-1}		
		<300 mm TPAW		
1988	34	64	83	76
	67	79	51	75
	101	55	85	98
1989	34	527	556	682
	67	570	597	620
	101	589	592	719
1990	34	848	882	970
	67	940	1026	1020
	101	928	945	1055
1991	34	815	899	1037
	67	867	866	987
	101	910	940	1191
		300–400 mm TPAW		
1985	34	2073	1959	2191
	67	1969	2001	2215
	101	1869	1937	2095
1987	34	909	1138	1313
	67	1147	1551	1751
	101	1148	1379	1763
1992	34	2568	3354	2585
	67	2513	2826	2408
	101	2817	3523	3505
1994	34	2099	2622	1590
	67	2194	2699	2173
	101	2024	2870	2344
1996	34	1502	1603	1725
	67	1621	1678	2264
	101	1492	1610	2451
		>400 mm TPAW		
1986	34	1445	1418	1372
	67	1979	1808	1641
	101	2176	2136	1857
1993	34	1595	1597	1550
	67	2154	2066	1927
	101	2109	2109	2293
1995	34	1518	1475	1136
	67	1747	1621	1414
	101	1664	1618	1360

† Interaction $LSD_{0.05}$ = 220 kg ha^{-1} (compare tillage within N × year); $LSD_{0.05}$ = 215 kg ha^{-1} (compare N rate within tillage × year).

‡ CT, conventional till; MT, minimum till; NT, no till.

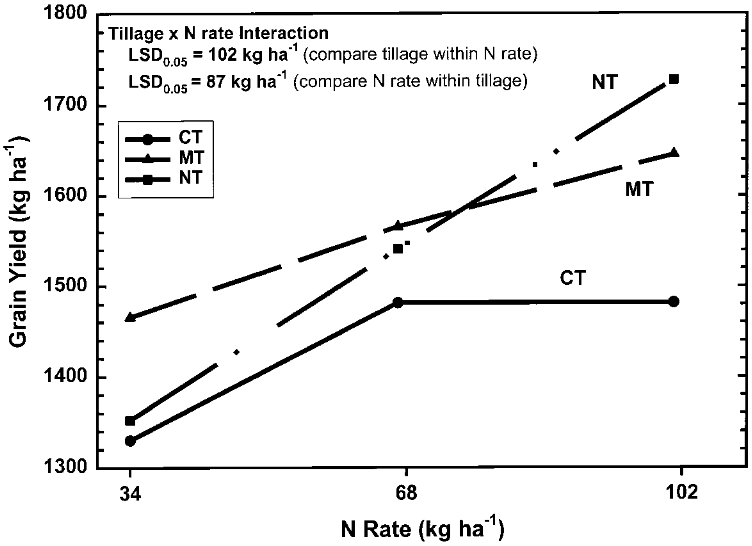

Fig. 4. Average 12-yr grain yield as a function of N rate for conventional-till (CT), minimum-till (MT), and no-till (NT) treatments.

NO_3–N than CT from 1990 through 1994. Average spring soil NO_3–N levels (0- to 120-cm depth) were 122, 113, and 65 kg N ha^{-1} for the CT, MT, and NT treatments, respectively. These trends probably reflect less N mineralization of soil organic matter in the NT system compared with the CT system, where tillage operations mix soil and crop residues. In fact, Wienhold and Halvorson (1998) showed that NT had a higher level of total N in the surface 15 cm of soil than MT and CT treatments after 10 crop years and that N mineralization potential (Wienhold and Halvorson, 1999) was greater with NT than with CT and MT.

The N rate × year interaction showed that spring soil NO_3–N levels were similar for all N rates from 1985 through 1988 (Fig. 3). In 1989, soil NO_3–N levels increased, with the greatest level of spring soil NO_3–N associated with the 101 kg ha^{-1} N rate. From 1989 through 1992, spring soil NO_3–N levels increased with increasing N rate. Soil NO_3–N levels began to decline in 1993 for all N rates, with the 34 and 67 kg ha^{-1} N rates declining to 1985 levels. No fertilization in 1991 and 1992 along with fair to good SF yields (Halvorson et al., 1999b) from 1991 through 1994 prior to SW probably contributed to this decline in spring soil N levels. Spring soil NO_3–N levels in 1994 were slightly greater than the 1993 levels for the 34 and 67 kg ha^{-1} N rates. All spring soil NO_3–N levels had declined to 1985 levels by 1996.

Grain Yield

Spring wheat grain yields were significantly affected by tillage system, N fertilization rate, cultivar, and years. However, significant tillage × N rate, tillage × year, N rate × year, cultivar × year, tillage × N rate × year, and N rate × cultivar × year interactions for grain yield were present. The yearly data was grouped by level of

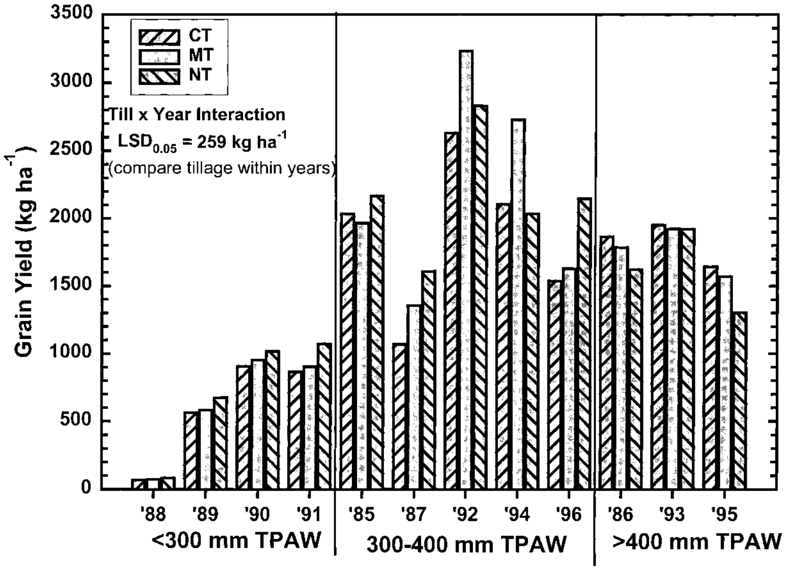

Fig. 5. Grain yield as a function of years, grouped by level of total plant available water (TPAW), for conventional-till (CT), minimum-till (MT), and no-till (NT) treatments.

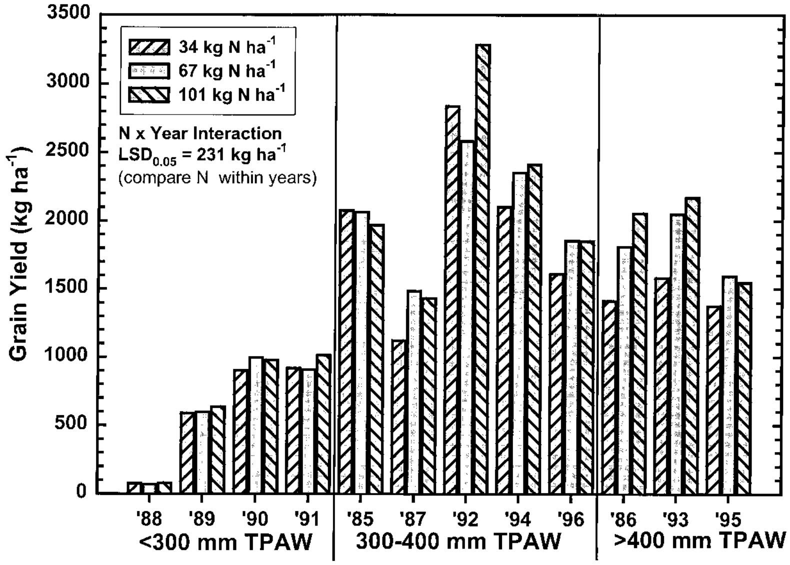

Fig. 6. Grain yield as a function of years, grouped by level of total plant available water (TPAW), for N rate treatments.

TPAW (<300 mm, 300–400 mm, and >400 mm) to show the relationship of TPAW on SW yields.

Grain yields for the tillage × N rate × year interaction are shown in Table 2. During the years with <300 mm TPAW, yields were lowest in 1988 and highest in 1991, with no differences among tillage treatments in 1988, 1989, and 1990 when compared across N rates and years. In 1991, grain yields with NT were greater than with CT at the low and high N rates. In general, responses to N rates were nonsignificant during the years with <300 mm TPAW; however, the greatest yields tended to be associated with NT and the highest N rate each year. Merrill et al. (1996) reported superior SW root growth in the NT system compared with the CT system, which would support the tendency for greater yields with NT.

During the years with 300 to 400 mm TPAW, grain yields (Table 2) were significantly higher with NT than with CT in 1985, 1987, and 1996 across all N rates, except for the low N rate in 1985. In 1987 and 1996, grain yields tended to increase with increasing N rates for NT, with no grain yield responses to N with CT and MT. In 1992 and 1994, grain yields with MT were greater than CT and NT over all N rates, except for the highest N rate in 1992 when NT yields equaled MT yields. In 1994, CT grain yields were greater than NT yields at the low N rate and NT yields were greater than CT yields at the high N rate. Yields in 1992 and 1994 tended to be the greatest at the highest N rate for MT and NT treatments. During the years when TPAW was <400 mm, NT and MT generally produced better grain yields than CT, partly because crop residue helped suppress evaporation so that the plants could use the water.

During the years with >400 mm TPAW, grain yields (Table 2) were similar for all tillage treatments at the lowest N rates in 1986 and 1993, with significantly greater yields with CT and MT than with NT at the highest N rate in 1986. Grain yields increased with increasing N rates for all tillage treatments in 1986 and 1993. In 1995, CT and MT grain yields exceeded those of NT at the lowest and highest N rates, with CT yields exceeding those of NT at the medium N rate. In 1995, grain yields were maximized with the medium N rate for all tillage treatments. Grain yield responses to applications of 67 and 101 kg N ha^{-1} tended to be greater in years when TPAW was >400 mm than in those years with less TPAW. The tendency for lower yields with NT in the wetter years in contrast to higher yields in

Table 3. Spring wheat grain yields for the N rate × cultivar × year interaction† as grouped by level of total plant available water (TPAW).

		Grain yield		
Year	Cultivar	34 kg N ha^{-1}	67 kg N ha^{-1}	101 kg N ha^{-1}
		<300 mm TPAW		
1988	Butte86	70	78	88
	Stoa	79	58	71
1989	Butte86	613	595	646
	Stoa	563	597	621
1990	Butte86	921	1060	1027
	Stoa	879	931	925
1991	Butte86	1059	984	1081
	Stoa	775	829	946
		300–400 mm TPAW		
1985	Butte86	2205	2121	1984
	Stoa	1944	2001	1950
1987	Butte86	1158	1593	1438
	Stoa	1082	1373	1422
1992	Butte86	2978	2788	3465
	Stoa	2693	2377	3099
1994	Butte86	2155	2399	2504
	Stoa	2052	2311	2320
1996	Butte86	1600	1964	1867
	Stoa	1620	1745	1835
		>400 mm TPAW		
1986	Butte86	1597	1912	2222
	Stoa	1226	1706	1890
1993	Butte86	1663	2209	2262
	Stoa	1498	1889	2079
1995	Butte86	1611	1803	1840
	Stoa	1142	1385	1255

† Interaction LSD$_{0.05}$ = 125 kg ha^{-1} (compare N rate within cultivar × year); LSD = 116 kg ha^{-1} (compare cultivar within N rates × year).

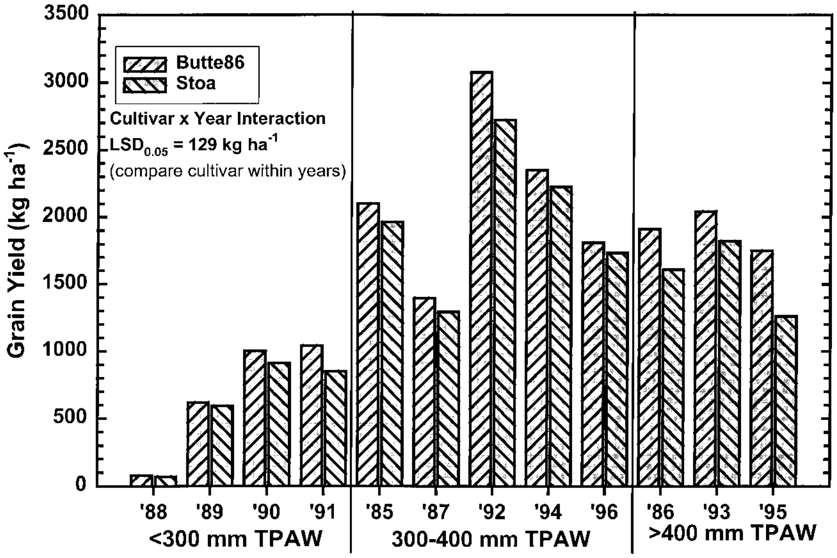

Fig. 7. Grain yield as a function years, grouped by level of total plant available water (TPAW), for spring wheat cultivars.

the drier years when compared with yields with CT and MT partly explains the significant tillage × N rate × year interaction. Residues were not as important to water conservation and evaporation suppression during years with >400 mm TPAW. In addition, responses to N at the two highest rates were probably minimized by the high level of spring soil N present at planting most years. Campbell et al. (1993a, b) reported that soil N became more important to SW yields than fertilizer N with increasing years of adequate N fertilization in an annual cropping system. This supports our observations in this study.

Grain yields in the >400 mm TPAW group were generally equal to or less than those within the 300 to 400 mm TPAW group. One reason for grain yields not increasing above those within the 300 to 400 mm TPAW group would be an increase in leaf spot disease severity associated with higher moisture levels, which reduced yield potential (Krupinsky et al., 1997, 1998). A contributing factor to lower yields at the 34 kg N ha^{-1} could be related to an increase in disease severity. When evaluating SW plants for leaf spot diseases during this study, differences among N treatments were evident for nearly half (45%) of the ratings. Higher levels of disease severity were associated with the 34 kg N ha^{-1} treatment compared with the higher N treatments. This indicated that N level had an influence on leaf spot diseases and emphasized the importance of providing adequate N nutrition in continuous cropping systems (Krupinsky et al., 1997, 1998).

The tillage × N interaction shows that SW grain yields with MT were greater than those with CT and NT at 34 kg ha^{-1} N (Fig. 4). Grain yields at the 101 kg ha^{-1} N rate were in the order NT = MT > CT. The greatest 12-yr average SW grain yield (1727 kg ha^{-1}) resulted with NT and the highest N rate. The benefit of using NT and MT systems over CT systems for SW production in an annual cropping system with adequate N fertilization is depicted in Fig. 4.

Discussion of the tillage × year (Fig. 5) and N rate × year (Fig. 6) interactions for grain yield will be minimal due to the extensive discussion of the tillage × N rate × year interaction above. Data trends observed in Fig. 5 and Fig. 6 are similar to those discussed above for the grain yield data in Table 2.

Grain yields for the N rate × cultivar × year interaction are reported in Table 3. During the years with <300 mm TPAW, there were no grain yield responses to N with Stoa; however, grain yields were maximized at the medium N rate with Butte86 in 1990. During the years with 300 to 400 mm TPAW, grain yield responses to N rate varied. In 1985, Stoa did not respond to N fertilization but Butte86 grain yields decreased with increasing N rate. In 1987, grain yields with the medium and high N rates exceeded those of the low N rate for both cultivars. In 1992, the low and high N rates produced a greater yield than with the medium N rate for both cultivars. In 1994 and 1996, the medium and high N rates produced higher yields than the low N rate for both cultivars. During the years with >400 mm TPAW, both cultivars obtained their greatest yields with the highest N rate, with the exception of Stoa in 1995. In 1993 and 1995, grain yields were similar for the medium and high N rates for Butte86. Grain yields at the medium N rate were greater than with the high or low N rates in 1995 for Stoa. In general, grain yields for Butte86 tended to be greater than those of Stoa at all N rates in 1985, 1991, 1992, 1993, and 1995.

The cultivar × year interaction effects on grain yields are shown in Fig. 7. Grain yields were greater for Butte86 than for Stoa in 1985, 1986, 1991, 1992, 1993, and 1995 (6 out of the 12 years of this study). Stoa grain yields equaled those of Butte86 during the other six years. In this study, Butte86 generally reached the heading and grain filling growth stages about 6 d earlier than Stoa, thereby escaping some of the effects of plant diseases and late summer drought stress. This may partially explain the greater yields with Butte86 over Stoa in some years. The overall impact of SW cultivar on grain yields in this study was small.

Grain yields for the NT, MT, and CT treatments averaged 1540, 1558, and 1431 kg ha^{-1}, respectively. Average grain yields were 1383, 1529, and 1618 kg ha^{-1} for the 34, 67, and 101 kg N ha^{-1} treatments, respectively. Grain yields for Butte86 and Stoa averaged 1599 and 1421 kg ha^{-1}, respectively.

SUMMARY

The results of this study show that SW grain yields following SF in rotation are generally enhanced using MT and NT systems compared with CT during most years with adequate N fertility. Grain yields tended to be greatest with NT compared with CT during those years with <400 mm TPAW. In wetter years, CT treatments generally produced greater SW yields than NT, particularly at low N rates. Leaf spot disease pressure was greater during the wetter years and at the low N rate (Krupinsky et al., 1997, 1998). The results show that during extremely dry years (e.g., 1988 through 1990), reduced tillage treatments did not store enough additional water to significantly enhance yield potential over that of the CT system. Responses to N fertilization were insignificant during these dry years, which resulted in increased residual spring soil NO_3–N levels. Responses to N fertilization were similar for both cultivars during the average and wetter years. Butte86 grain yields were greater than those of Stoa in 6 out of 12 years, three of which were years with >400 mm TPAW and two years with 300 to 400 mm TPAW. Grain yields were similar for both cultivars for all other years. The highest 12-yr average grain yield was obtained with the highest N rate and NT.

Spring wheat yield responses in this study are in agreement with annual cropping SW yields reported by Aase and Schaefer (1996) using NT, Halvorson and Black (1985), and Black et al. (1981) in northeastern Montana. In 6 out of the 12 years in this study, spring wheat yields exceeded the average 2-yr, SW–fallow yields (1737 kg ha^{-1}) reported for five southcentral North Dakota counties near the study site for 1989 through 1996 (Beard and Hamlin, 1995; Beard and Waldhaus, 1997). In two years, yields were 77 and 87% of SW–fallow yields; in two years, yields were 54% of SW–fallow yields; and in two years, yields were about 34% of SW–fallow yields.

These results indicate that farmers in the northern Great Plains can successfully produce SW following SF in annual cropping rotations that do not include a fallow period. During production periods with low soil water recharge following sunflower in rotation, farmers may want to consider producing a crop with lower water-use requirements than spring wheat to avoid uneconomical spring wheat yields. Fallow following sunflower should be considered as the last alternative because of a high soil erosion potential.

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Cover Crops for Sweet Corn Production in a Short-Season Environment

Tim Griffin*, Matt Liebman, and John Jemison Jr.

ABSTRACT

Legume cover crops can supply all or most of the N required by a subsequent crop if legume biomass is of sufficient quantity and N mineralization is approximately synchronous with crop demand. Three 2-yr crop rotation cycles were conducted on a Lamoine silt loam (fine, illitic, nonacid, frigid Aeric Epiaquept) soil in Maine to (i) evaluate biomass and N accumulation of alfalfa (*Medicago sativa* L.), winter rye (*Secale cereale* L.), and hairy vetch (*Vicia villosa* Roth subsp. *villosa*) plus winter rye cover crops; (ii) determine sweet corn (*Zea mays* L.) response to legume and fertilizer N sources in a barley (*Hordeum vulgare* L.)–sweet corn rotation; and (iii) assess the accuracy of the presidedress soil nitrate test (PSNT) and leaf chlorophyll N test (LCNT) for distinguishing N-responsive and nonresponsive sweet corn. Both legumes accumulated more N than rye grown alone, although total biomass was similar. Sweet corn following rye always exhibited a linear response to N fertilizer (up to 156 kg N ha^{-1}), but generally exhibited no response to added N following either alfalfa or hairy vetch plus winter rye (VR). Both PSNT and LCNT were 75% accurate in identifying plots responsive to additional fertilizer N. The legume cover crops grown were able to replace all or nearly all of the N fertilizer required by a subsequent sweet corn crop, with fertilizer replacement values (FRVs) of 58 to 156 kg N ha^{-1} in a short-season environment. These cover crops are a viable alternative source of N, greatly reducing or eliminating the need for N fertilizer.

PRODUCTION systems that utilize N-fixing legumes as a primary N source for subsequent nonlegume crops include full-season green manure crops, interseeded legumes, and cover crops. Each of these options present significant management challenges to producers interested in reducing fertilizer N inputs or producing crops without fertilizer N. For example, full-season green manure crops, while potentially having the greatest impact on soil quality and pest/weed cycles (Altieri, 1995; Biederbeck et al., 1998), may not be economically viable because of the loss of income from that field for an entire growing season. Interseeding legumes with or into a standing crop is common in small grains like wheat (*Triticum aestivum* L.) and oat (*Avena sativa* L.). Brulsema and Christie (1987), Hesterman et al. (1992), and Stute and Posner (1995) demonstrated that this system can result in significant contributions of N to a subsequent corn crop. However, interseeding into a widely spaced row crop like corn or soybean [*Glycine max* (L.) Merr] may require specialized equipment and additional field operations, and competition between the interseeded and main crops also can be problematic (Kumwenda et al., 1993).

Cover crops, generally grown over the winter between harvest of one crop and planting of a subsequent crop, can overcome at least some of the obstacles associated with green manure and interseeded crops. It is well-documented that cover crops can supply sufficient N for production of a subsequent grain crop with little or no supplemental N fertilizer. McVay et al. (1989) found minimal corn yield response to N fertilizer following hairy vetch or crimson clover (*Trifoilium incarnatum* L.) cover crops, compared with corn following wheat. Burket et al. (1997) compared sweet corn yield following clover (*Trifolium pratense* L.), rye, and rye plus pea

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T. Griffin and J. Jemison Jr., Cooperative Extension, University of Maine, 495 College Avenue., Orono, ME 04473-1294. M. Liebman, Department of Agronomy, 3218 Agronomy Hall, Iowa State University, Ames, IA 50011-1010. Maine Agric. Forest Exp. Stn. Publ. 2367. Partial Funding from USDA-SARE, Project ANE92-31. Received 3 May 1999. *Corresponding author (tgriffin@umext.maine.edu).

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Abbreviations: FRV, fertilizer replacement value; LCNT, leaf chlorophyll N test; PSNT, presidedress soil nitrate test; VR, hairy vetch plus winter rye; DM, dry matter.