Tillage and Crop Rotation Effects on Dryland Soil and Residue Carbon and Nitrogen

Upendra M. Sainju,* Andrew Lenssen, Thecan Caesar-Tonthat, and Jed Waddell

ABSTRACT

Sustainable management practices are needed to enhance soil productivity in degraded dryland soils in the northern Great Plains. We examined the effects of two tillage practices [conventional till (CT) and no-till (NT)], five crop rotations [continuous spring wheat (*Triticum aestivum* L.) (CW), spring wheat-fallow (W-F), spring wheat-lentil (*Lens culinaris* Medic.) (W-L), spring wheat-spring wheat-fallow (W-W-F), and spring wheat-pea (*Pisum sativum* L.)-fallow (W-P-F)], and a Conservation Reserve Program (CRP) on plant biomass returned to the soil, residue C and N, and soil organic C (SOC), soil total N (STN), and particulate organic C and N (POC and PON) at the 0- to 20-cm depth. A field experiment was conducted in a mixture of Scobey clay loam (fine, smectitic, frigid Aridic Argiustolls) and Kevin clay loam (fine-loamy, mixed, superactive, frigid Aridic Argiustolls) from 1998 to 2003 near Havre, MT. Mean annualized plant biomass returned to the soil from 1998 to 2003 was greater in W-F (2.02 Mg ha^{-1}) than in W-L and W-W-F, regardless of tillage. In 2004, residue cover was greater in CW (60%) than in other rotations, except in W-W-F. Residue amount and C and N contents were greater in NT with CW (2.47 Mg ha^{-1} and 963 and 22 kg ha^{-1}, respectively) than in NT with W-L and CT with other crop rotations. The POC at 0 to 5 cm was greater in W-W-F and W-P-F (2.1–2.2 Mg ha^{-1}) than in W-L. Similarly, STN at 5 to 20 cm was greater in CT with W-L (2.21 Mg ha^{-1}) than in other treatments, except in NT with W-W-F. Reduced tillage and increased cropping intensity, such as NT with CW and W-L, conserved C and N in dryland soils and crop residue better than the traditional practice, CT with W-F, and their contents were similar to or better than in CRP planting.

CONVENTIONAL TILLAGE and wheat-fallow systems have been traditional farming practices in northern Great Plains for a long time (Haas et al., 1957). Studies have shown that during the last 50 to 100 yr of cultivation in this semiarid region, SOC and STN have declined by 30 to 50% of their original levels (Haas et al., 1957; Campbell and Souster, 1982; Mann, 1985; Peterson et al., 1998). Intensive tillage increases the oxidation of soil organic matter (Follett and Schimel, 1989; Bowman et al., 1999; Schomberg and Jones, 1999) and fallowing increases its loss by reducing the amount of plant residue returned to the soil (Black and Tanaka, 1997; Campbell et al., 2000; West and Post, 2002). Although expanding fallow increases soil water storage and crop yields (Eck and Jones, 1992; Jones and Popham, 1997), increased soil water and temperature during fallowing can also accelerate mineralization of SOC and STN (Haas et al., 1974). As a result, the traditional system of farming has become unsustainable partly due to increased dependence of producers on federal aids (Aase and Schaefer, 1996; Dhuyvetter et al., 1996; Krall and Schuman, 1996).

Improved soil and crop management practices that reduce tillage intensity, increase the amount of plant residue returned to the soil, and adapt to the harsh environmental conditions of northern Great Plains are needed to increase soil organic matter and the sustainability of the farming system. Studies have shown that NT with increased cropping intensity can increase SOC and STN compared to CT with W-F system in the drylands of central Great Plains (Halvorson et al., 2002a; Sherrod et al., 2003; Allmaras et al., 2004). Halvorson et al. (2002b) observed that NT with continuous cropping increased C sequestration in the drylands of northern Great Plains by 233 kg ha^{-1} yr^{-1} compared with a loss of 141 kg ha^{-1} yr^{-1} in CT. They pointed out that continued use of crop-fallow system even in NT increased SOC loss. Similarly, Sherrod et al. (2003) reported that increased cropping intensity in NT increased SOC and STN in drylands of central Great Plains after 12 yr. After analyzing data from long-term experiments in various locations, West and Post (2002) concluded that conversion from CT to NT can sequester an average of 570 ± 140 kg C ha^{-1} yr^{-1}, reaching equilibrium in 15 to 20 yr and enhanced crop rotation can sequester 200 ± 120 kg C ha^{-1} yr^{-1}, reaching equilibrium in 40 to 60 yr. The benefits of increasing SOC and STN lie not only in enhancing soil structure and soil water-nutrient-crop productivity relationships (Bauer and Black, 1994), but also includes the ability of the soil to store atmospheric C and N, thereby reducing the concentration of greenhouse gases, such as CO_2 and N_2O (Paustian et al., 1997; Janzen et al., 1999; Lal et al., 1998, 1999).

Limited volume of soil water content is a major factor for dryland crop production in the Great Plains. The use of NT has allowed producers to increase cropping intensity (Aase and Schaefer, 1996; Halvorson et al., 1999, 2000; Peterson et al., 2001), because NT conserves surface residues and retains water in the soil profile more than CT does (Farhani et al., 1998). As a result, soil water can be used more efficiently by crops in NT (Deibert et al., 1986; Peterson et al., 1996), which can reduce or eliminate summer fallow by growing continuous crops (Peterson et al., 1993, 2001; Farhani et al., 1998). In NT, winter wheat yield in wheat-corn (*Zea mays* L.)-fallow rotation is greater or similar to that in wheat-fallow rotation, thereby making the NT system more profitable (Halvorson et al., 1994, 2002a; Dhuyvetter et al., 1996). As a result, the NT system provides better opportunities to sustain crop yields by growing

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USDA-ARS, 1500 North Central Avenue, Sidney, MT 59270. Received 25 Mar. 2005. *Corresponding author (usainju@sidney.ars.usda.gov).

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677 S. Segoe Rd., Madison, WI 53711 USA

Abbreviations: CRP, Conservation Reserve Program; CT, conventional till; CW, continuous spring wheat; NT, no-till; POC, particulate organic C; PON, particulate organic N; SOC, soil organic C; STN, soil total N; W-F, spring wheat-fallow; W-L, spring wheat-lentil; W-P-F, spring wheat-pea-fallow; W-W-F, spring wheat-spring wheat-fallow.

more crops and to conserve soil C and N than the CT system in the drylands of Great Plains.

Because of limited water and cold weather, crop yields and biomass production are often lower in the Great Plains than in subhumid regions (Halvorson et al., 2002a). As a result, the amount of crop residue returned to the soil is also lower, thereby requiring more time to enrich SOC and STN (Halvorson et al., 2002a; Sherrod et al., 2003). Halvorson et al. (2002a) and Ortega et al. (2002) did not observe significant increases in SOC and STN under continuous wheat compared with wheat-fallow in NT after 4 to 8 yr in central Great Plains, but Sherrod et al. (2003) found significant increases with continuous cropping only after 12 yr. Crop residue inputs are directly related to differences in SOC among cropping systems (Collins et al., 1992; Campbell et al., 1992; Campbell and Zentner, 1993). The balance between the amount of residue input and its rate of decomposition in the soil as influenced by tillage determines SOC and STN levels (Rasmussen et al., 1980; Havlin et al., 1990; Peterson et al., 1998). Therefore, increased cropping intensity together with reduced tillage can enhance SOC and STN levels even in semiarid regions (West and Post, 2002; Halvorson et al., 2002a; Peterson et al., 1998).

Because more time is required to enhance soil organic matter level in drylands, information on long-term tillage and cropping systems on SOC and STN is often limited in northern Great Plains. Although information is available for the central Great Plains (Halvorson et al., 2002a; Ortega et al., 2002; Sherrod et al., 2003), they may not be applicable to northern Great Plains because of the difference in temperature, rainfall, and growing degree days. Similarly, few studies have concentrated on the effects of crop rotation and tillage on intermediate pools of soil C and N, such as POC and PON. Soil organic matter that changes slowly over time may not be influenced by crop rotation, but dynamic soil properties, such as POC and PON, can vary among rotations due to differences in crop yields and residue inputs as a result of differences in cultural practices, year-to-year variations in growing environment, or the length of fallow period since last residue was returned to the soil (Campbell et al., 1992). While SOC and STN contain most of the nonlabile fractions of soil C and N that change slowly over time, POC and PON are considered as intermediate pools between active and passive fractions of soil organic matter that change rapidly over time due to changes in management practices, such as tillage and recent addition of crop residue (Cambardella and Elliott, 1992; Chan, 1997; Bayer et al., 2001). The POC and PON also provide substrates for microorganisms and influence soil aggregation (Beare et al., 1994; Franzluebbers et al., 1999; Six et al., 1999). We hypothesized that NT with crop rotation containing increased cropping intensity and a shorter fallow period since last residue was returned to the soil can increase SOC, STN, POC, and PON compared to CT with W-F system. Our objectives were to: (i) examine the influence of 6 yr of tillage and crop rotations on crop biomass production, residue cover, amount, C and N contents, and SOC, STN, POC and PON contents at the 0- to 5- and 5- to 20-cm depths in drylands in northern Great Plains, (ii) quantify tillage and crop rotation effects on retention of C and N in soil and crop residue, and (iii) compare organic matter levels in cropland and CRP planting.

MATERIALS AND METHODS

Site Description

The experimental site was located on a private farm (48° 48′ N, 110° 1′ W, altitude 886 m) about 56 km WNW of Havre, MT. The site is characterized by wide variation in mean monthly air temperature from −10°C in January to 21°C in July and August and an annual rainfall of 305 mm. The soil consisted of a mixture of Scobey clay loam with 0 to 4% slope and Kevin clay loam with 2 to 4% slope. The soil sampled in April 1998 before the initiation of the experiment contained 530 g kg^{-1} sand, 210 g kg^{-1} silt, 260 g kg^{-1} clay, 1.31 Mg m^{-3} bulk density, 20.5 Mg ha^{-1} organic C, 2.23 Mg ha^{-1} total N, and 8.3 pH at the 0- to 20-cm depth. The site was enrolled in the Conservation Reserve Program from 1986 to 1997, with undisturbed vegetation of crested wheatgrass [*Agropyron cristatum* (L.) Gaertn] and alfalfa (*Medicago sativa* L.). Resident vegetation was killed in 1997 by applying glyphosate [N-(phosphonomethyl) glycine)] at 0.84 kg a.i. ha^{-1}.

Treatments

The treatments consisted of two tillage practices (CT and NT), nine crop rotations and/or sequences with 1-, 2-, and 3-yr rotations, and a CRP planting. For simplicity, cropping sequences, such as CW, W-F, and W-W-F, will be hereafter called as 1-yr, 2-yr, and 3-year crop rotations, respectively. The 1-yr crop rotation consisted of CW. The 2-yr rotations contained W-F and W-L. Similarly, the 3-yr rotations contained W-W-F, W-P-F, yellow mustard (*Sinapis alba* L.)–spring wheat–fallow, spring wheat–safflower (*Carthamus tinctorius* L.)–fallow, chickpea (*Cicer arietinum* L.)–spring wheat–fallow, and spring wheat–sunflower (*Helianthus annuus* L)–pea. Since some of the crops in the rotation failed for several years, only five rotations that contained significant biomass yields in all years were selected for this study (Table 1). In the crop rotation treatment, crops used are relevant to northern Great Plains. Each phase of the crop rotation was present in every year. From 1998 to 2003, the 1-yr rotation completed six cycles, 2-yr rotations three cycles, and 3-yr rotations two cycles. The CRP

Table 1. Crop species used in rotation from 1998 to 2003 in the study site.

Crop rotation†	1998	1999	2000	2001	2002	2003
CRP	**CRP**	**CRP**	**CRP**	**CRP**	**CRP**	**CRP**
CW	**Spring wheat**	**Spring wheat**	**Spring wheat**	**Spring wheat**	**Spring wheat**	**Spring wheat**
W-F	**Spring wheat**	**Fallow**	**Spring wheat**	**Fallow**	**Spring wheat**	**Fallow**
W-L	**Spring wheat**	**Lentil**	**Spring wheat**	**Lentil**	**Spring wheat**	**Lentil**
W-W-F	**Spring wheat**	**Spring wheat**	**Fallow**	**Spring wheat**	**Spring wheat**	**Fallow**
W-P-F	**Spring wheat**	**Pea**	**Fallow**	**Spring wheat**	**Pea**	**Fallow**

consisted of a mixture of alfalfa (*Medicago sativa* L.) and three grasses consisting of western wheatgrass [*Pascopyron* smithii (Rydb.) A. Love], slender wheatgrass [*Elmus trachycaulus* (Link.) Gould ex Shinners], and green needlegrass [*Nassella viridula* (Trin.) Backworth]. All crops in the rotations and plants in CRP were planted in CT and NT. The CT plots were cultivated with standard sweeps and rods (model 1600, John Deere Co., Moline, IL) to a depth of 10 cm. The NT plots were left undisturbed, except for drilling seeds and fertilizers. Weeds in these plots were controlled by applying glyphosate [N-(phosphonomethyl) glycine)] at 0.84 kg a.i. ha^{-1} before and after crop planting and with appropriate herbicides for each crop during its growth. The CT plots in CRP were cultivated before planting in 1998, after which no further tillage was done. The experiment was arranged in a randomized complete block in a split-plot arrangement. Tillage was the main-plot factor and crop rotation was the split-plot factor. Each treatment was replicated four times. However, for this study, only three replications were selected because of crop damage in the fourth replication. Individual plot size was 14.6 × 30.4 m. Replications were separated by 24.3 × 30.4 m alleys.

Crop Management

Before planting crops in April and May of each year from 1998 to 2003, two soil core (5 cm i.d.) samples were collected from the 0- to 60-cm depth from each plot in October of the previous year after fall crop harvest, which were composited for NO_3–N analysis. Based on soil NO_3–N content and spring wheat yield goal of 2350 kg ha^{-1} and 13% protein content, N fertilizer was applied from 0 to 78 kg N ha^{-1} yr^{-1} to spring wheat in various rotations in CT and NT from 1998 to 2003. Fertilizer N rate was calculated as per Montana State University recommendations by deducting soil NO_3–N content at the 0- to 60-cm depth from the 118 kg N ha^{-1} requirement for spring wheat. Nitrogen was also applied to pea and lentil at 6 kg N ha^{-1} while applying P as monoammonium phosphate (11% N, 23% P) in each year because it was the only P fertilizer available to satisfy P requirement for crops. Total rate of N fertilization to spring wheat, pea, and lentil in each rotation in CT and NT from 1998 to 2003 varied from 100 to 266 kg N ha^{-1}. Nitrogen was applied as urea (46% N) and monoammonium phosphate. Based on soil test results, fertilizer P (as monoammonium phosphate) was applied at 56 kg ha^{-1}, and K (as muriate of potash, 60% K) at 48 kg ha^{-1} to spring wheat, pea, and lentil each year. All fertilizers were banded at a depth of 5 to 7 cm with a single-pass ConservaPak (model 129A, ConservaPak Seeding Systems, Saskatchewan, Canada) air seeder at planting.

Spring wheat [cv. McNeal in 1998 and 1999, cv. Amidon in 2000, and cv. Scholar from 2001 to 2003 (all from Foundation Seed, Montana State Univ.)] was planted at 60 to 70 kg ha^{-1}, pea (cv. Alfetta in 1998 and 1999 [Mark Peterson Land and Cattle, Inc., Havre, MT] and cv. Majorete from 2000 to 2003 [Macintosh Seed, Havre, MT]) at 161 to 258 kg ha^{-1}, and lentil (cv. Richlea from 1998 to 2002 and cv. Indianhead in 2003 [both from Macintosh Seed, Havre, MT]) at 45 to 110 kg ha^{-1} in April and May of every year. The cultivars of spring wheat, pea, and lentil were changed during the course of the experiment to reduce pest susceptibility and damage during seed handling and to increase germination percentage, yields, and economic returns from crops. Because of different seed sizes, seed rates also varied for each cultivar of spring wheat, pea, and lentil to achieve desirable plant stands (spring wheat, 215; pea, 97; and lentil, 129 plants m^{-2}). Changes in cultivars and seed rates of crops will influence the amount of biomass residues returned to the soil and SOC, POC, STN, and PON levels. Spring wheat was planted at a depth of 4 to 5 cm and pea and lentil planted at 3 to 6 cm with a ConservaPak air seeder, depending on the depth of moist soil each year. Seeds were placed at 2 cm above the depth of the fertilizer in the soil. In CRP, alfalfa, western wheatgrass, slender wheatgrass, and green needlegrass were planted at 2.2 kg ha^{-1} each in April 1998. No fertilizers were applied to plants in CRP. Growing season weeds were controlled with selective preplant herbicides appropriate for each crop. Contact herbicides were applied at postharvest, except in 1998 and 1999 when CT plots were tilled with sweeps. Similarly, weed control in summer fallow CT plots used sweep tillage, while fallow plots in NT were treated with glyphosate at 0.84 kg a.i. ha^{-1}.

Plant and Soil Sample Collection

Before grain harvest in July and August, total crop biomass (grains + stems + leaves) yield in each year was measured on a 30 × 100 cm area within each plot. After separating grains, biomass (stems + leaves) samples were dried in the oven at 55°C and dry matter yield was determined. Grain yield was determined (pea in July and spring wheat and lentil in August) by harvesting an area of 1.5 × 30.4 m with a self-propelled combine (model 6600, John Deere Co., Moline, IL). Grain yields were converted into dry matter basis after a sample was dried in the oven at 60°C. The remaining residues containing stems and leaves were returned to the soil. Post-harvest crop residue cover in each plot was determined by using the USDA-NRCS point-method of counting 100 points per plot by a 15 m long string with each point at 0.15 m spacing (Shelton et al., 1993).

In March 2004, crop residue amount was collected from five 30 × 30 cm areas randomly in the central rows of the plot, composited, washed with water to remove soil, and dried in the oven at 60°C to obtain dry matter weight. Samples were ground to pass a 1-mm screen before C and N analysis. After removing the residue from the soil surface, soil samples were collected with a hand probe (5-cm i.d.) from the 0- to 20-cm depth from five places in the central rows of the plot, separated into the 0- to 5- and 5- to 20-cm depths, and composited within a depth. Samples were air-dried, ground, and sieved to 2 mm for determining C and N concentrations. A separate soil core (5-cm i.d.) was taken from the 0- to 5- and the 5- to 20-cm depths from each plot to determine bulk density.

Carbon and Nitrogen Analysis

Total C and N concentrations in crop residue were determined by using a C and N analyzer (Model 661–900–800, LECO Corp., St. Joseph, MI). Carbon and N contents in the residue were determined by multiplying dry matter weight by C and N concentrations. The SOC concentration was determined by using the C and N analyzer after pretreating the soil with 5% (v/v) H_2SO_3 to remove inorganic C (Nelson and Sommers, 1996). The STN was determined by using the analyzer as above without pretreating the soil with acid. For determining POC and PON, 10 g soil was dispersed with 30 mL of 5 g L^{-1} sodium hexametaphosphate for 16 h and the solution was poured through a 0.05-mm sieve (Cambardella and Elliott, 1992). The solution and particles that passed through the sieve were dried at 50°C for 3 to 4 d and organic C and N concentrations were determined by using the analyzer as above. The POC concentration was determined by the difference between organic C in whole-soil and that in the particles that passed through the sieve after correcting for the sand content. Similarly, PON concentration was determined as the difference between STN in the whole-soil and that in the particles that passed through the sieve after correcting for the sand content. The contents of SOC, STN, POC, and PON at the 0- to 5- and 5- to 20-cm depths were calculated by multiplying their concentrations by bulk density and thickness of the soil layer. Because bulk density was influenced by tillage but not by crop rotation and its interaction with tillage, bulk density values of 1.24 and 1.32 Mg ha^{-1} for CT and NT, respectively, at 0 to 5 cm and 1.32 and 1.34 Mg ha^{-1} at 5 to 20 cm, averaged across crop rotations, were used for the calculation. The total contents of SOC, STN, POC, and PON at the 0- to 20-cm depth were determined by summing the contents at the 0- to 5- and 5- to 20-cm depths.

Data Analysis

Data for plant biomass returned to the soil in each year from 1998 to 2003 and mean annualized biomass as influenced by tillage and crop rotation were analyzed using the analysis of covariance in MIXED procedure of SAS (Littell et al., 1996) after considering N fertilization rate and rainfall as covariate factors. This is done to eliminate the variations due to N rates and annual rainfall on the amount of plant biomass returned to the soil. Similarly, data for crop residue cover, amount, and C and N contents, and SOC, STN, POC and PON contents were analyzed using the analysis of covariance with N rate as the covariate factor. Since crop residue and soil samples were collected in March 2004 and all treatments received equal amount of rainfall, rainfall was not considered as another covariate factor in the analysis of residue and soil data. Tillage and crop rotation were considered as fixed effects and replication and tillage × replication interaction were considered as random effects. Since each phase of crop rotation was present in every year, data for phases were averaged within a rotation and the averaged value was used for a crop rotation for the analysis. Means were separated by using the least square means test when treatments and interaction were significant. Statistical significance was evaluated at $P \leq 0.05$, unless otherwise stated. The values for CRP planting were used only for comparing with those from tillage and crop rotation treatments and not for statistical analysis of data. This is done because one of the objectives of the experiment was to compare C and N contents in plant residue and soil under croplands and CRP planting.

RESULTS AND DISCUSSION

Crop Biomass Yield

Crop rotation significantly ($P \leq 0.05$) influenced biomass (stems + leaves) yield of spring wheat, pea, and lentil residues returned to the soil from 1998 to 2003 (Table 2). Crop biomass yield differed between crop rotations in each year, except in 2000. For example, crop biomass, averaged across tillage, was significantly higher in W-F in 2001 and in CW in 2002 than in other crop rotations. Similarly, biomass was higher in CW than in W-L in 2003. Biomass yields were lower in 2001 than in 2000, 2002, and 2003. This could be due to the difference in the amount of water available in the soil during crop growth. Soil water storage has been reported to be higher following fallow in W-F system due to reduced transpiration loss by plants during fallow (Farhani et al., 1998; Halvorson et al., 2002a). Although greater wheat biomass yield in CW than in W-F and W-W-F in 2002 was attributed to increased cropping intensity in relatively moist period, increased biomass yield in W-F in 2001 could be due to increased moisture conservation following fallow in drier period. Total rainfall during the growing season from April to August was 159, 99, 83, 220, 131, and 203 mm in 1999, 2000, 2001, 2002, 2003, and the 87-yr average, respectively (Table 3). The monthly

Table 2. Effects of tillage and crop rotation on biomass (stems + leaves) yield of crops from 1998 to 2003.

Treatment	1998†	1999†	2000	2001	2002	2003	Mean‡	Mean§
	Mg ha^{-1}							
				Tillage¶				
CT	4.05a#	2.92a	1.53a	0.32a	1.69a	1.29a	1.58a	1.23a
NT	4.31a	2.99a	1.74a	0.47a	2.00a	1.50a	1.78a	1.49a
				Crop rotation††				
CW	5.55	3.60	1.88	0.39	2.73	1.71	1.96	1.77
W-F	2.82	3.06	1.39	0.63	1.24	1.54	2.02	1.53
W-L	5.39	2.02	1.66	0.21	2.25	0.88	1.35	1.11
W-W-F	3.64	3.18	1.30	0.34	1.82	1.38	1.53	1.17
W-P-F	3.52	2.90	1.94	0.40	1.18	1.44	1.55	1.22
LSD (0.05)	0.82	0.87	—	0.21	0.43	0.41	0.48	0.52
CRP‡‡	—	—	—	—	—	1.84	—	—
				Analysis of covariance				
	$P > F$							
Tillage (T)	0.467	0.796	0.342	0.201	0.147	0.380	0.803	0.719
Crop rotation (C)	0.001	0.021	0.109	0.052	<0.001	0.004	<0.001	0.005
T × C	0.679	0.802	0.975	0.732	0.091	0.232	0.983	0.954
N rate (N)	NE§§	NE	NE	NE	NE	NE	<0.001	0.008
N × T × C	NE	NE	NE	NE	NE	NE	0.001	0.005
Rainfall (R)	NE	NE	NE	NE	NE	NE	0.340	0.010
R × T × C	NE	NE	NE	NE	NE	NE	0.011	0.027

† Biomass yield for 1998 and 1999 were projected from their grain yield and the average biomass yield: grain yield ratio from 2000 to 2003.
‡ Mean annualized biomass yield from 1998 to 2003.
§ Mean annualized biomass yield from 2000 to 2003.
¶ CT, conventional till; NT, no-till.
# Numbers followed by same letters within a tillage treatment are not significantly different at $P = 0.05$ by the least square means test.
†† Crop rotation is: CW, continuous spring wheat; W-F, spring wheat-fallow; W-L, spring wheat-lentil; W-P-F, spring wheat-pea-fallow; and W-W-F, spring wheat-spring wheat-fallow.
‡‡ Values for CRP (conservation reserve program) are shown for comparison only and not used in the statistical analysis of data.
§§ Non-estimable.

Table 3. Mean monthly temperature and total monthly rainfall during the growing season from April to August, 1999 to 2003 near the experimental site.

	Temperature						Rainfall					
Month	**1999**	**2000**	**2001**	**2002**	**2003**	**87-yr average**	**1999**	**2000**	**2001**	**2002**	**2003**	**87-yr average**
	°C						mm					
April	3.0	6.1	5.6	2.6	7.7	6.7	10.0	12.2	15.0	2.8	36.3	24.6
May	10.0	12.4	10.0	8.9	10.8	12.7	30.0	24.4	20.0	35.8	27.9	44.7
June	16.7	14.8	17.4	16.0	15.8	17.1	40.0	49.3	14.7	111.5	38.1	65.0
July	17.8	21.9	21.5	21.3	22.7	21.2	43.4	9.7	10.4	26.7	5.1	37.8
August	20.0	20.5	22.0	16.1	22.6	20.2	35.3	3.0	23.1	43.2	23.6	31.0
Total	—	—	—	—	—	—	158.7	98.6	83.2	220.0	131.0	203.1

average air temperature was similar to long-term normal but a record 112 mm rain fell during June 2002 compared with 65 mm for the 87-yr average (Table 3). As a result, crop biomass yields were higher in 2002 and lower in 2001 than in other years, except in 1998 and 1999 where biomass yields were predicted by multiplying their grain yields with average biomass yield/grain yield ratios from 2000 to 2003 (Table 2). Since the values in 1998 and 1999 were much larger than those obtained from 2000 to 2003, it may be possible that biomass yields in 1998 and 1999 were overestimated. Biomass yield of plants in CRP was measured only in 2003. Tillage did not influence biomass yield of crops. Because biomass yields of crops were absent (0 Mg ha^{-1}) during fallow, variances due to N fertilization rate and rainfall as covariate factors on crop biomass within a year were not estimable.

Variances due to N rate, rainfall, and their interactions with tillage and crop rotation were significant ($P \leq 0.05$) for the mean annualized biomass yields from 1998 to 2003 and 2000 to 2003 (Table 2). Annualized biomass yield, averaged across tillage and years from 1998 to 2003 and adjusted for N rate and rainfall, was significantly ($P \leq 0.5$) greater in W-F than in W-L and W-W-F. When biomass from 1998 and 1999 were excluded, annualized biomass was greater in CW than in other rotations, except in W-F. This indicates that the amount of crop biomass residue returned to the soil either increased with increase in cropping intensity, as reported by others (Halvorson et al., 2002a; Ortega et al., 2002; Sherrod et al., 2003), or soil water conservation following fallow probably increased biomass yield of spring wheat in W-F. Mean annualized biomass yield, averaged across crop rotation, was not influenced by tillage.

Crop Residue Cover, Amount, and Carbon and Nitrogen

Variable N rates applied to crops significantly ($P \leq 0.01$) interacted with tillage and crop rotation on crop residue cover (Table 4). Eliminating the effect of N rate, tillage and crop rotation significantly ($P < 0.05$) influenced crop residue cover. More residue cover in NT than in CT was accumulated at the soil surface because CT incorporates residue into the soil. As with biomass production, residue cover varied between crop rotations. Residue cover was higher in CW than in other crop rotations, except in W-W-F. This is because of the difference in the amount of crop biomass returned to the soil and application frequency, which varied with the length of fallow period among crop rotations. The mean

Table 4. Effects of tillage and crop rotation on the percentage of crop residue cover, residue amount, and C and N contents in 2004.

				Concentration		Content		
Treatment	**Time since last residue addition**	**Residue cover**	**Residue amount**	**C**	**N**	**C**	**N**	**C/N ratio cover**
	mo	%	Mg ha^{-1}	g kg^{-1}		kg ha^{-1}		
			Tillage†					
CT	—	43b‡	1.06a	372a	8.8a	394a	9.3a	42a
NT	—	57a	1.87a	394a	8.1a	736a	15.1a	49a
			Crop rotation§					
CW	8	60	1.45	365	8.3	529	12.0	44
W-F	20	18	1.01	367	9.1	380	7.2	42
W-L	8	6	0.53	385	9.5	213	3.1	43
W-W-F	12	53	1.71	379	9.0	653	14.9	45
W-P-F	13	24	0.45	330	9.6	154	4.2	36
LSD (0.05)	—	25	1.17	—	1.0	380	10.5	10
CRP¶	—	94	2.73	427	9.1	1165	24.8	47
			Analysis of covariance					
		$P > F$						
Tillage (T)		0.037	0.653	0.308	0.478	0.561	0.416	0.773
Crop rotation (C)		0.026	0.032	0.212	0.045	0.016	0.025	0.013
T × C		0.180	<0.001	0.651	0.623	0.002	<0.001	0.603
N rate × T × C		0.002	<0.001	<0.001	0.021	<0.001	<0.001	<0.001

† CT, conventional till; NT, no-till.

‡ Numbers followed by same letters within a tillage treatment are not significantly different at $P \leq 0.05$ by the least square means test.

§ Crop rotation is: CW, continuous spring wheat; W-F, spring wheat-fallow; W-L, spring wheat-lentil; W-P-F, spring wheat-pea-fallow; and W-W-F, spring wheat-spring wheat-fallow.

¶ Values for CRP (conservation reserve program) are shown for comparison only and not used in the statistical analysis of data.

Table 5. Interacting effects of tillage and crop rotation on the percentage of crop residue cover, residue amount, and C and N contents in 2004.

				Concentration		Content		
Tillage†	**Crop rotation‡**	**Residue cover**	**Residue amount**	**C**	**N**	**C**	**N**	**C/N ratio**
		%	Mg ha^{-1}	g kg^{-1}		kg ha^{-1}		
CT	CW	28	0.44	339	7.6	149	3.3	45
	W-F	18	1.01	364	12.0	367	12.1	31
	W-L	6	0.53	390	11.2	206	5.9	35
	W-W-F	53	1.71	371	8.9	634	15.2	42
	W-P-F	24	0.45	339	9.8	152	4.4	35
NT	CW	60	2.47	390	9.0	963	22.2	43
	W-F	23	1.92	371	6.2	712	11.9	60
	W-L	47	1.23	380	7.8	467	9.6	49
	W-W-F	61	2.31	386	9.2	892	21.3	42
	W-P-F	35	0.66	321	9.4	212	6.2	34
LSD (0.05)		–	1.15	–	–	327	7.2	–
CT§	CRP§	97	2.63	423	11.7	1112	30.8	36
NT§	CRP§	77	2.83	431	6.5	1220	18.4	66

† CT, conventional till; NT, no-till.

‡ Crop rotation is: CRP, conservation reserve program (contains alfalfa, green needlegrass, western wheatgrass, and slender wheatgrass); CW, continuous spring wheat; W-F, spring wheat-fallow; W-L, spring wheat-lentil; W-P-F, spring wheat-pea-fallow; and W-W-F, spring wheat-spring wheat-fallow.

§ Values for CT-CRP and NT-CRP are shown for comparison only and not used in the statistical analysis of data.

annualized biomass returned to the soil was higher in CW than in W-L when biomass from 1998 to 2003 was considered or higher in CW than in other rotations, except in W-F, when biomass from 2000 to 2003 were considered (Table 2). Similarly, the length of fallow period since the last residue was returned to the soil was 8 mo in CW compared with 20 mo in W-F, 12 mo in W-W-F, and 13 mo in W-P-F (Table 4). The longer fallow period increased the decomposition of biomass residue in the soil, thereby resulting in low residue cover in the rotation containing fallow. The fallow period is a time of high microbial activity and decomposition of organic matter with no input of crop residue (Halvorson et al., 2002b). Even with continuous cropping, residue cover in CW was only 64% of that in CRP. The higher residue cover in CRP was due to continuous ground coverage by perennial forages throughout the year, even in CT where tillage was discontinued after planting alfalfa and grasses.

Nitrogen rate also interacted significantly ($P \leq 0.001$) with tillage and crop rotation on crop residue amount and C and N contents (Table 4) by influencing on the amount of plant biomass residue returned to the soil (Table 3). Eliminating the effect of N rate, differences in residue amount between crop rotations in CT and NT led to a significant ($P \leq 0.001$) tillage × crop rotation interaction (Tables 4 and 5). Residue amount was higher in W-W-F than in other crop rotations, except in W-F, in CT but was higher in CW than in W-L and W-P-F in NT (Table 5). Similarly, residue amount was higher in NT

Table 6. Effects of tillage and crop rotation on soil organic C (SOC) and particulate organic C (POC) contents at the 0- to 20-cm depth in 2004.

		SOC content at soil depth, cm			POC content at soil depth, cm			POC/SOC ratio at soil depth, cm		
Tillage†	**Crop rotation‡**	**0 to 5**	**5 to 20**	**0 to 20**	**0 to 5**	**5 to 20**	**0 to 20**	**0 to 5**	**5 to 20**	**0 to 20**
		Mg C ha^{-1}						g kg^{-1} SOC		
CT	CW	5.5	13.9	19.4	1.6	4.5	6.1	288	317	310
	W-F	5.3	15.3	20.6	1.6	3.7	5.3	304	243	259
	W-L	4.9	17.7	22.6	1.0	3.2	4.2	222	160	175
	W-W-F	5.0	14.0	19.0	2.0	4.8	6.8	394	342	356
	W-P-F	5.4	14.9	20.3	2.0	5.3	7.3	378	349	358
NT	CW	6.5	14.4	20.9	2.4	5.0	7.4	370	345	353
	W-F	6.1	13.0	19.1	2.0	4.5	6.5	338	354	351
	W-L	5.7	12.7	18.4	1.8	4.8	5.6	309	377	351
	W-W-F	7.2	16.1	23.3	2.4	5.2	7.6	334	316	357
	W-P-F	6.3	14.5	20.8	2.2	4.7	6.9	344	328	333
LSD (0.05)		–	–	–	–	–	–	–	38	73
CT§	CRP§	6.0	13.8	19.8	2.2	4.9	7.1	364	351	357
NT§	CRP§	6.4	15.9	22.3	1.9	5.5	7.4	304	394	330
		Analysis of covariance								
		$P > F$								
Tillage (T)		0.532	0.439	0.653	0.428	0.567	0.445	0.572	0.076	0.664
Crop rotation (C)		0.277	0.783	0.612	0.045	0.517	0.240	0.043	0.034	0.080
T × C		0.805	0.402	0.426	0.836	0.792	0.715	0.660	0.034	0.027
N rate × T × C		0.805	0.871	0.830	0.255	0.560	0.328	0.130	0.007	0.002

† CT, conventional till; NT, no-till.

‡ Crop rotation is: CW, continuous spring wheat; W-F, spring wheat-fallow; W-L, spring wheat-lentil; W-P-F, spring wheat-pea-fallow; and W-W-F, spring wheat-spring wheat-fallow.

§ Values for CT-CRP (conservation reserve program) and NT-CRP are shown for comparison only and not used in the statistical analysis of data.

with CW than in other treatments, except in CT with W-W-F, NT with W-F, and NT with W-W-F. Since there was no significant tillage × crop rotation interaction in the amount of crop biomass returned to the soil (Table 2), the difference in the residue amount between crop rotations in CT and NT could be due to variations in the amount of biomass returned to the soil among crop rotations, followed by their different decomposition rates due to tillage. Also, the difference in the length of fallow period since the last residue was returned to the soil could influence residue amount between crop rotations. For example, greater amount of crop biomass returned to the soil (Table 2) could have increased residue amount in CW compared with W-L and W-P-F in NT but increased biomass, followed by slower decomposition rates of the residue (a function of residue quality, such as its C/N ratio) could have resulted in greater residue amount in W-W-F than in other crop rotations in CT. Our results are consistent with those observed by Ortega et al. (2002) who reported that the amount of residue left on the soil surface is influenced by biomass production of crops and their microbial degradation in the soil, and that the amount of residue increased with increasing cropping intensity in NT. Similarly, Schomberg and Jones (1999) reported that the amount of crop residue is increased as the length of the fallow period is decreased. Increase in cropping intensity with the inclusion of legumes, such as lentil and pea, in the rotation (W-L vs. W-P-F), however, did not increase mean annualized amount of biomass residue returned to the soil (Table 2) and residue amount (Table 5). Regardless of tillage, residue amount was greater in W-W-F than in W-L and W-P-F (Table 4). Considering that the amount of residue lost or gained due to actions of wind and water is negligible, the amount of residue left in the soil after 6 yr varied from 2% of the total biomass returned to the soil in W-L in CT to 21% in W-W-F in NT. The lower amount of residue in W-L and W-P-F could be due to lower biomass of lentil and pea returned to the soil compared with spring wheat (Table 2), followed by their rapid decomposition in the soil. Legumes, such as pea and lentil, with lower C/N ratio decompose rapidly in the soil compared with nonlegumes (Wagger et al., 1985; Aulakh et al., 1991; Kuo et al., 1996). Although residue amount was lower in crop rotations than in CRP in CT, it amounted to 87% of CRP in CW in NT.

Carbon concentration in the residue was not influenced by tillage and crop rotation but N concentration was higher in W-P-F than in CW (Table 4). Tillage × crop rotation interaction was significant ($P \leq 0.01$) for C and N contents in the residue. Similar to residue amount, C and N contents in the residue were higher in W-W-F than in other crop rotations, except in W-F, in CT but were higher in CW than in W-L and W-P-F in NT (Table 5). As a result, C and N can be conserved in the residue using NT with CW and CT with W-W-F better than in other treatments. With reduced tillage and continuous cropping, such as in NT with CW, C and N can be conserved in the residue at levels close to that in CRP plantings. The C/N ratio of the residue was not influenced by tillage and crop rotation and averaged 42, which can immobilize N in the soil (Allison and Klein, 1962; Wagger et al., 1985).

Soil Carbon

Eliminating the variance due to N rate, SOC was not influenced by tillage and crop rotation (Table 6). Similarly, tillage × crop rotation and N rate × tillage × crop rotation interactions were not significant for SOC. Although SOC was greater in NT than in CT and greater amounts of crop residue were returned to the soil in CW than in other rotations, tillage and crop rotation did not influence SOC. Halvorson et al. (2002a) found that increased crop biomass residue returned to the soil with continuous corn or wheat-corn-fallow rotation did not increase SOC compared with W-F in NT or CT after 5 yr in central Great Plains. Similarly, Ortega et al. (2002) reported that SOC was not significantly influenced by

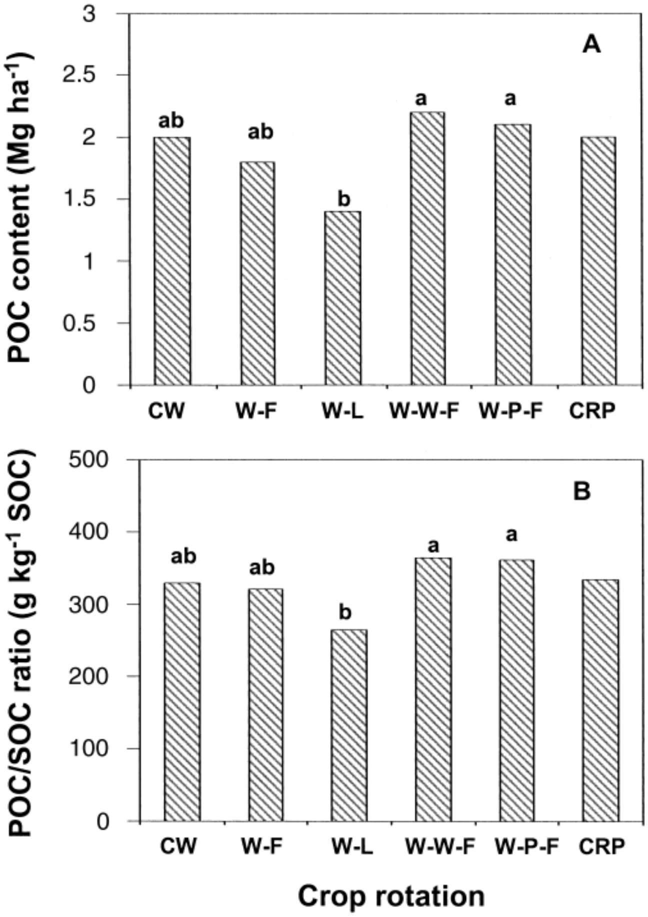

Fig. 1. (A) Soil particulate organic C (POC) content and (B) POC/soil organic C (SOC) ratio at the 0- to 5-cm depth, averaged across tillage, as influenced by crop rotation. Crop rotation is CW, continuous spring wheat (*Triticum aestivum* L.); W-F, spring wheat-fallow; W-L, spring wheat-lentil (*Lens culinaris* Medic.); W-P-F, spring wheat-pea (*Pisum sativum* L.)-fallow; and W-W-F, spring wheat-spring wheat-fallow. Bars followed by the same letter at the top are not significantly different at $P \leq 0.05$ by the least square means test. Values for conservation reserve program (CRP) are shown for comparison only and not used in the statistical analysis of data.

crop rotation in NT after 8 yr in the central Great Plains, even though continuous cropping returned greater biomass residue to the soil compared with crop rotations containing fallow. However, Sherrod et al. (2003) reported that increased cropping intensity increased SOC in the central Great Plains only after 12 yr. Perhaps longer time than the present 6 yr of study may be needed to observe changes in SOC due to tillage and crop rotation in the northern Great Plains.

The POC at the 0- to 5-cm depth was significantly ($P \leq 0.05$) influenced by crop rotation but tillage, tillage × crop rotation, and N rate × tillage × crop rotation were not significant (Table 6). The POC at 0 to 5 cm, averaged across tillage, was higher in W-W-F and W-P-F than in W-L (Fig. 1A). Since the mean annualized amount of crop biomass returned to the soil were similar in W-W-F, W-P-F, and W-L (Table 2), the differences in POC between these rotations could be due to difference in biomass residue quality (such as C/N ratio, a factor that was not measured in this experiment) which could influence their decomposition rates in the soil. It could be possible that residues in W-L had lower C/N ratio than that in W-W-F and W-P-F. Since POC represents coarse fraction of organic matter held between soil particles (Cambardella and Elliott, 1992), it could be possible that coarse organic fraction in W-W-F and W-P-F decomposed slower than that in W-L, thereby resulting in higher POC. The POC at 0 to 5 cm in W-W-F and W-P-F was similar to or higher than that in CRP (Fig. 1A).

The POC/SOC ratio at 0 to 5 and 5 to 20 cm was significantly ($P \leq 0.05$) influenced by crop rotation (Table 6). The tillage × crop rotation and N rate × tillage × crop rotation interactions were significant ($P \leq 0.05$) for POC/SOC ratio at 5 to 20 and 0 to 20 cm. As with POC, the POC/SOC ratio at 0 to 5 cm was higher in W-W-F and W-P-F than in W-L (Fig. 1B). At 5 to 20 cm, the ratio was higher in W-P-F than in W-F and W-L in CT but was higher in W-L than in W-W-F and W-P-F in NT (Table 6). Similarly, at 0 to 20 cm, the ratio was higher in W-P-F than in W-F and W-L in CT but was not different between crop rotations in NT.

Since SOC was not influenced by tillage and crop rotation, significant effects of crop rotation and tillage × crop rotation interaction on POC/SOC ratio suggests that POC changes more rapidly than SOC due to changes in soil and crop management practices, such as tillage and crop rotation. Higher POC/SOC ratio at 0 to 5 cm in W-W-F and W-P-F than in W-L was probably due to greater POC in these rotations, as observed above (Fig. 1A), while SOC was remaining at the same level. Similarly higher POC/SOC in W-P-F than in W-F and W-L in CT could be due to greater turnover rate of biomass residue into POC compared with SOC in this rotation as a result of difference in decomposition rates of residue due to tillage. Without tillage, turnover rate of biomass residue into POC compared with SOC was probably higher in W-L than in W-W-F and W-P-F, thereby resulting in greater POC/SOC ratio in W-L in NT. The proportion of SOC in POC in W-W-F, W-P-F, and W-L in CT and NT were comparable with that in CRP in CT and NT.

Soil Nitrogen

As with SOC, eliminating the variance due to N rate, a significant ($P \leq 0.05$) tillage × crop rotation interaction occurred for STN at the 5- to 20-cm depth (Table 7). The STN at 5 to 20 cm was greater in W-L than in other crop rotations in CT and greater in W-W-F than in W-F in NT. The greater STN at 5 to 20 cm in W-L than in other crop rotations in CT could be due to increased cropping intensity, followed by incorporation of legume residues,

Table 7. Effects of tillage and crop rotation on soil total N (STN) and particulate organic N (PON) contents at the 0- to 20-cm depth in 2004.

		STN content at soil depth, cm			PON content at soil depth, cm			PON/STN ratio at soil depth, cm		
Tillage†	**Crop rotation‡**	**0 to 5**	**5 to 20**	**0 to 20**	**0 to 5**	**5 to 20**	**0 to 20**	**0 to 5**	**5 to 20**	**0 to 20**
		Mg N ha^{-1}						g kg^{-1} STN		
CT	CW	0.54	1.49	2.03	0.14	0.51	0.65	247	339	316
	W-F	0.62	1.70	2.32	0.20	0.52	0.72	318	302	308
	W-L	0.66	2.21	2.87	0.18	0.64	0.82	285	282	279
	W-W-F	0.61	1.40	2.01	0.24	0.50	0.74	397	339	369
	W-P-F	0.66	1.63	2.29	0.25	0.60	0.85	372	363	369
NT	CW	1.08	1.56	2.64	0.42	0.46	0.88	380	308	345
	W-F	0.92	1.41	2.33	0.32	0.50	0.82	354	376	366
	W-L	0.56	1.55	2.61	0.14	0.61	0.75	283	406	366
	W-W-F	0.81	1.89	2.70	0.24	0.71	0.95	321	371	357
	W-P-F	0.70	1.55	2.25	0.26	0.56	0.82	334	360	352
LSD (0.05)		—	0.37	—	—	—	—	—	—	—
CT§	CRP§	0.75	1.50	2.25	0.28	0.59	0.87	370	393	387
NT§	CRP§	0.84	1.70	2.54	0.27	0.64	0.91	319	377	355
					Analysis of covariance					
						$P > F$				
Tillage (T)		0.723	0.667	0.623	0.640	0.575	0.837	0.702	0.264	0.293
Crop rotation (C)		0.748	0.144	0.434	0.614	0.242	0.311	0.229	0.519	0.079
T × C		0.527	0.032	0.141	0.471	0.061	0.127	0.609	0.686	0.545
N rate × T × C		0.509	0.191	0.346	0.287	0.228	0.071	0.288	0.526	0.053

† Tillage is CT, conventional till; and NT, no-till.

‡ Crop rotation is: CW, continuous spring wheat; W-F, spring wheat-fallow; W-L, spring wheat-lentil; W-P-F, spring wheat-pea-fallow; and W-W-F, spring wheat-spring wheat-fallow.

§ Values for CT-CRP (conservation reserve program) and NT-CRP are shown for comparison only and not used in the statistical analysis of data.

Table 8. Effects of tillage and crop rotation on soil organic C (SOC)/total N (STN) ratio and particulate organic C (POC)/particulate organic N (PON) ratio at the 0- to 20-cm depth in 2004.

		SOC/STN ratio at soil depth, cm			POC/PON ratio at soil depth, cm		
Tillage†	**Crop rotation‡**	**0 to 5**	**5 to 20**	**0 to 20**	**0 to 5**	**5 to 20**	**0 to 20**
CT	**CW**	**10.4**	**9.3**	**9.6**	**12.8**	**8.7**	**9.4**
	W-F	**8.5**	**9.1**	**8.9**	**8.2**	**7.3**	**7.5**
	W-L	**7.6**	**7.8**	**7.7**	**5.8**	**4.2**	**4.8**
	W-W-F	**8.3**	**10.6**	**9.7**	**8.3**	**10.2**	**9.4**
	W-P-F	**8.3**	**9.1**	**8.9**	**8.4**	**8.7**	**8.6**
NT	**CW**	**6.9**	**9.3**	**8.2**	**6.8**	**11.8**	**8.4**
	W-F	**6.2**	**9.3**	**8.1**	**5.9**	**8.7**	**7.9**
	W-L	**9.6**	**8.2**	**8.7**	**10.4**	**7.6**	**8.4**
	W-W-F	**8.9**	**9.6**	**8.7**	**9.3**	**7.3**	**7.8**
	W-P-F	**9.1**	**9.4**	**9.2**	**9.5**	**8.7**	**8.8**
LSD (0.05)		**—**	**—**	**—**	**—**	**—**	**—**
CT§	**CRP§**	**7.9**	**9.3**	**8.8**	**7.8**	**8.4**	**8.2**
NT§	**CRP§**	**7.6**	**9.5**	**8.8**	**7.2**	**8.6**	**8.2**
			Analysis of covariance				
					P* > *F		
Tillage (T)		**0.404**	**0.625**	**0.989**	**0.167**	**0.969**	**0.578**
Crop rotation (C)		**0.669**	**0.769**	**0.837**	**0.562**	**0.534**	**0.359**
T × C		**0.221**	**0.244**	**0.550**	**0.120**	**0.201**	**0.140**
N rate × T × C		**0.153**	**0.361**	**0.378**	**0.141**	**0.375**	**0.099**

† CT, conventional till;NT, no-till.

‡ Crop rotation is: CW, continuous spring wheat; W-F, spring wheat-fallow; W-L, spring wheat-lentil; W-P-F, spring wheat-pea-fallow; and W-W-F, spring wheat-spring wheat-fallow.

§ Values for CT-CRP (conservation reserve program) and NT-CRP are shown for comparison only and not used in the statistical analysis of data.

such as lentil, containing high N concentration to a greater depth with tillage. Similarly, greater STN at 5 to 20 cm in W-W-F than in W-F in NT could be due to increased cropping intensity. Our results are similar to those found by Sherrod et al. (2003) who reported that increased cropping intensity in NT increased soil organic N after 12 yr in central Great Plains. The STN levels at 5 to 20 cm in W-L in CT and in W-W-F in NT were similar to or higher than those in CRP in CT and NT, suggesting that increased cropping intensity can increase STN in the subsurface soil similar to or greater than that in CRP planting, regardless of tillage. Tillage, crop rotation, and their interaction were not significant for PON and PON/STN ratio.

Relationship between Soil Carbon and Nitrogen

With the elimination of variance due to N rate, tillage, crop rotation, and their interaction were not significant for SOC/STN and POC/PON ratios (Table 8). Averaged across treatments, SOC/STN ratios were 8.4 at 0 to 5 cm, 9.2 at 5 to 20 cm, and 8.8 at 0 to 20 cm. Similarly, POC/PON ratios were 8.5 at 0 to 5 cm, 8.3 at 5 to 20 cm, and 8.1 at 0 to 20 cm. These values were similar to those obtained for CRP (7.6 to 9.5 for SOC/STN and 7.2 to 8.6 for POC/PON ratios at 0 to 20 cm). The results suggest that C and N in whole soil and particulate organic matter mineralize at same rates, thereby resulting in similar C/N ratios, regardless of tillage, crop rotations, and cropping system.

CONCLUSIONS

Results from this study showed that tillage and crop rotation influenced the amount of crop biomass residue returned to the soil, residue cover, amount, and C and N contents, and soil organic matter after 6 yr. Biomass increased as cropping intensity increased but varied within crop rotations and years. As a result, residue cover, amount, and C and N contents also varied with crop rotations and tillage but normally increased with reduced tillage and increased cropping intensity. The POC at 0 to 5 cm was greater in W-W-F and W-P-F than in W-L but STN at 5 to 20 cm was greater in W-L than in other crop rotations in CT and greater in W-W-F than in W-F in NT. The quality, quantity, and rate of mineralization of biomass residue returned to the soil at various depths as influenced by crop species, cropping intensity, and tillage probably influenced soil C and N levels. Reduced tillage and increased cropping intensity can conserve C and N in dryland soil and crop residues better than the traditional CT with W-F system in northern Great Plains. Carbon and N in crop residue and soil under croplands can be preserved at levels similar to those under CRP planting that had been continued for the last 16 yr. For dryland soils using conservation tillage and increased cropping intensity, we measured no significant changes in C and N storage during a 6-yr study because of the lower amount of annualized biomass residue returned to the soil and reduced turnover rate than reported in the subhumid regions.

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