Dryland plant biomass and soil carbon and nitrogen fractions on transient land as influenced by tillage and crop rotation

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Abstract

Soil and crop management practices may alter the quantity, quality, and placement of plant residues that influence soil C and N fractions. We examined the effects of two tillage practices [conventional till (CT) and no-till (NT)] and 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)] on transient land previously under 10 years of Conservation Reserve Program (CRP) planting on the amount of plant biomass (stems + leaves) returned to the soil from 1998 to 2003 and soil C and N fractions within the surface 20 cm in March 2004. A continued CRP planting was also included as another treatment for comparing soil C and N fractions. The C and N fractions included soil organic C (SOC), soil total N (STN), microbial biomass C and N (MBC and MBN), potential C and N mineralization (PCM and PNM), and NH4-N and NO3-N contents. A field experiment was conducted in a mixture of Scobey clay loam (fine-loamy, mixed, Aridic Argiborolls) and Kevin clay loam (fine, montmorillonitic, Aridic Argiborolls) in Havre, MT, USA. Plant biomass yield varied by crop rotation and year and mean annualized biomass was 45–50% higher in CW and W–F than in W–L. The SOC and PCM were not influenced by treatments. The MBC at 0–5 cm was 26% higher in W–W–F than in W–F. The STN and NO3-N at 5–20 cm and PNM at 0–5 cm were 17–1206% higher in CT with W–L than in other treatments. Similarly, MBN at 0–5 cm was higher in CT with W–L than in other treatments, except in CT with W–F and W–P–F. Reduction in the length of fallow period increased MBC and MBN but the presence of legumes, such as lentil and pea, in the crop rotation increased soil N fractions. Six years of tillage and crop rotation had minor influence on soil C and N storage between croplands and CRP planting but large differences in active soil C and N fractions. Published by Elsevier B.V.

Keywords: Crop rotation; Plant biomass; Carbon fractions; Nitrogen fractions; Tillage

1. Introduction

Soil organic matter is an important component of soil quality and productivity, but its measurement alone does not adequately reflect changes in soil quality and nutrient status (Franzluebbers et al., 1995; Bezdicek et al., 1996). This is because soil organic C (SOC) has large pool size and inherent spatial variability (Franzluebbers et al., 1995). Measurement of biologically active fractions of organic matter, such as microbial biomass C and N (MBC and MBN) and potential C and N mineralization (PCM and PNM), that change rapidly with time, could better reflect changes in soil quality and productivity that alter nutrient dynamics (Saffigna et al., 1989; Bremner and Van Kessel, 1992). These fractions can provide an assessment of soil organic matter changes induced by management practices, such as tillage and cropping system (Campbell et al., 1989).
Soil and crop management practices can alter the quantity, quality, and placement of crop residues in soil, thereby influencing microbial dynamics and supply of nutrients, such as N, through changes in mineralization–immobilization (Ghidey and Alberts, 1993). As a result, crop growth and yield can be significantly affected (Doran and Smith, 1987). Tillage can disturb soil aggregation and incorporate crop residues to a greater depth, which results in rapid decomposition as compared to their surface placement in no-till (NT) (Ghidey and Alberts, 1993; Halvorson et al., 2002a,b). Similarly, cropping system can affect the quantity and quality (C/N ratio) of crop residue and roots returned to the soil (Ghidey and Alberts, 1993). Crops grown in rotation often have higher biomass yield than those grown in monoculture (Copeland and Crookston, 1992). Similarly, crop rotations with shorter fallow periods often return more crop residue to the soil compared to rotations with longer fallow periods (Halvorson et al., 2002a,b). This alters soil microbial activity and N mineralization due to changes in organic matter turnover and MBN (Bonde and Rosswall, 1987; Bremner and Van Kessel, 1992) as a result of changes in soil moisture and temperature (Ross, 1987).

Reduced tillage and increased cropping intensity can increase soil C and N fractions. Several researchers (Arshad et al., 1990; Staley, 1999) have reported increased MBC at the soil surface in NT compared with CT, with similar or lower levels below 5.0–7.5 cm depth. Continuous wheat with decreased fallow period had greater MBC than wheat–fallow rotation after 30–58 years (Campbell et al., 1991; Collins et al., 1992). The MBC was greater in wheat–pea–forage rotation than in wheat–fallow in conventional till (CT) but similar in all crop sequences in NT (Granatstein et al., 1987). Similarly, Franzluebbers et al. (1994, 1995) reported that MBC, MBN, PCM, and PNM were greater in NT than in CT at the 0–5 cm depth, greater with rotated than with continuous sorghum (Sorghum bicolor L.), and increased with increasing cropping intensity after 9 years in south-central Texas. Doyle et al. (2004) also found greater MBC, MBN, and PCM in NT than in CT at 0–5 cm and greater with continuous sorghum than with continuous soybean (Glycine max (L.) Merill) after 27 years in Kansas. Increased cropping intensity with reduced fallow periods in NT increased dryland soil C fractions at levels close to those in perennial grasslands (Sherrod et al., 2005).

Increased residue accumulation, followed by higher level of MBC at the soil surface in NT, can enhance N immobilization (Doran et al., 1998; Zibilske et al., 2002), thereby resulting in a need for greater rate of N fertilization to crops (Bronson et al., 2001). Conversion of CRP land into cultivation also can result in N immobilization (Dao et al., 2002). In contrast, N fertilization rate for optimal crop production is often reduced in rotations containing legumes compared with monoculture nonlegume cropping system (Heichel and Barnes, 1984). This could be partly explained by greater labile N fractions, such as MBN and PNM, or greater turnover rate of organic matter in crop rotations (Franzluebbers et al., 1994, 1995). Wood et al. (1990) found that soil profile NO$_3$-N content decreased with increased cropping intensity due to greater N immobilization, less summer fallow, and greater amount of N removed by crops. Increasing fallow period can increase N loss below the root zone due to leaching and absence of crops to conserve N (Eck and Jones, 1992; Campbell and Zentner, 1993).

Grasslands represent one of the potential sites to store SOC and soil total N (STN) due to greater plant C and N inputs from above- and belowground biomass than in croplands (Cambardella and Elliott, 1992; Six et al., 1998). Therefore, comparison of soil C and N fractions in croplands with those in grasslands provides an index of the status of C and N levels.

Little information is available about the long-term effects of tillage and cropping system on soil C and N fractions in drylands of the northern Great Plains. Since the amount of plant residue returned to the soil in the northern Great Plains is lower due to limited rainfall and shorter growing season, it may take longer time to enrich soil organic matter than in the humid region of the southern US (Halvorson et al., 2002a,b; Sherrod et al., 2003, 2005). Because active soil C and N fractions change rapidly over time, we hypothesized that MBC, MBN, PCM, and PNM contents would respond significantly to tillage and crop rotations in drylands of the northern Great Plains. Our objectives were to: (1) quantify plant (stems + leaves) residue returned to the soil from 1998 to 2003 as influenced by tillage and crop rotations in drylands of the northern Great Plains, (2) determine their effects on SOC, STN, MBC, MBN, PCM, PNM, NH$_4$-N, and NO$_3$-N contents at 0–5 and 5–20 cm depths, and (3) compare soil C and N levels in croplands and a CRP planting.

2. Materials and methods

2.1. Plant and soil sampling and treatments

Plant and soil samples were collected from a tillage and crop rotation experiment from 1998 to 2003 in land previously managed for 10 years under CRP planting.
{undisturbed vegetation of crested wheatgrass [Agropyron cristatum (L.) Gaertn] and alfalfa (Medicago sativa L.)} in Havre, MT, USA. The site (48°48’N, 110°1’W, altitude 886 m) was characterized by mean monthly air temperature of −10 °C in January and 21 °C in July and August and an annual rainfall of 305 mm. The soil consisted of a mixture of Scobey clay loam (fine-loamy mixed Ardic Argiborolls) with 0–4% slope and Kevin clay loam (fine, montmorillonitic Ardic Argiborolls) with 2–4% slope. Soil sampled in April 1998 prior to 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 0–20 cm depth.

Treatments consisted of two tillage practices [conventional till (CT) and no-till (NT)], five crop rotations and/or sequences with 1–3 years rotations, and a Conservation Reserve Program (CRP) planting. The 1-year cropping sequence consisted of continuous spring wheat (Triticum aestivum L.) (CW), 2-year rotations were spring wheat–fallow (W–F) and spring wheat–lentil (Lens culinaris Medic.) (W–L), and 3-year rotations were spring wheat–spring wheat–fallow (W–W–F) and spring wheat–pea (Pisum sativum L.)–fallow (W–P–F). Each phase of the crop rotation was present in every year. From 1998 to 2003, the 1-year rotation completed six cycles, 2-year rotations three cycles, and 3-year rotations two cycles. The CRP consisted of a mixture of alfalfa and three grasses including western wheatgrass [Pascopyrum 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 No. 1600, John Dereee Co., Moline, IL) after pretreating the soil with 5% H₂SO₃ to remove inorganic C (Nelson and Sommers, 1996). The STN was determined by using the analyzer as above without pretreating the soil with acid. The PCM was determined with a high induction furnace C and N analyzer (LECO, St. Joseph, MI) after pretreating the soil with 5% H₂SO₃ to remove inorganic C (Nelson and Sommers, 1996). The SOC concentration (g kg⁻¹) was determined with a high induction furnace C and N analyzer (LECO, St. Joseph, MI) after pretreating the soil with 5% H₂SO₃ to remove inorganic C (Nelson and Sommers, 1996). The STN was determined by using the analyzer as above without pretreating the soil with acid. The PCM and PNM in air-dried soils were determined by the method modified by Haney et al. (2004). Two 10 g soil subsamples were moistened with water at 50% field capacity and placed in a 1 L jar containing beakers with 4 mL of 0.5 M NaOH to trap evolved CO₂ and 20 mL of water to maintain high humidity. Soils were incubated in the jar at 21 °C for 7 days. At 7 days, the beaker containing NaOH was removed from the jar and PCM was determined by measuring CO₂ absorbed in NaOH, which was back-titrated with 1.5 M BaCl₂ and 0.1 M HCl. One beaker containing soil was removed from the jar and extracted with 100 mL of 2 M KCl for 1 h. The NH₄-N and NO₃-N concentrations in the extract were determined by using autoanalyzer (Lachat Instrument,
Loveland, CO). The PNM was calculated as the difference between the sum of NH$_4$-N and NO$_3$-N concentrations in the soil before and after incubation.

The other beaker containing moist soil and incubated for 7 days (used for PCM determination above) was used for determining MBC and MBN by the modified fumigation–incubation method for air-dried soils (Franzluebbers et al., 1996). The moist soil was fumigated with ethanol-free chloroform for 24 h and placed in a 1 L jar containing beakers with 2 mL of 0.5 M NaOH and 20 mL water. As with PCM, fumigated moist soil was incubated for 7 days and CO$_2$ absorbed in NaOH was back-titrated with BaCl$_2$ and HCl. The MBC was calculated by dividing the amount of CO$_2$–C absorbed in NaOH by a factor of 0.41 (Voroney and Paul, 1982) without subtracting the values from the nonfumigated control (Franzluebbers et al., 1996). For MBN, the fumigated–incubated sample at 7 days was extracted with 100 mL of 2 M KCl for 1 h and 1996). For MBN, the fumigated–incubated sample at 7 days and CO$_2$ absorbed in NaOH was back-titrated with BaCl$_2$ and HCl. The MBC was calculated by dividing the amount of CO$_2$–C absorbed in NaOH by a factor of 0.41 (Voroney and Paul, 1982) without subtracting the values from the nonfumigated control (Franzluebbers et al., 1996). For MBN, the fumigated–incubated sample at 7 days was extracted with 100 mL of 2 M KCl for 1 h and NH$_4$-N and NO$_3$-N concentrations were determined by autoanalyzer as above. The MBN was calculated by the difference between the sum of NH$_4$-N and NO$_3$-N concentrations in the sample before and after fumigation–incubation and divided by a factor of 0.41 (Brookes et al., 1985; Voroney and Paul, 1982). The NH$_4$-N and NO$_3$-N concentrations determined in the nonfumigated–nonincubated samples were used as available fractions of N.

The contents (Mg ha$^{-1}$ or kg ha$^{-1}$) of SOC, STN, PCM, PNM, MBC, MBN, NH$_4$-N, and NO$_3$-N at the 0–5 and 5–20 cm depths were calculated by multiplying their concentrations by bulk density and soil depth after using proper conversion units. 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 0–5 cm and 1.32 and 1.34 Mg ha$^{-1}$ at 5–20 cm, averaged across crop rotations, were used for the calculation. The total contents at the 0–20 cm depth were determined by summing the contents at the 0–5 and 5–20 cm depths.

2.3. Data analysis

Data for crop residue produced in each year from 1998 to 2003 and soil C and N fractions in 2004 were analyzed using the MIXED procedure of SAS (Littell et al., 1996). 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. Data for soil C and N fractions in CRP planting were used only for comparing with those from croplands and not for statistical analysis of data.

3. Results and discussion

3.1. Crop residue production

Crop rotation significantly influenced crop residue production of spring wheat, pea, and lentil from 1998 to 2003 (Table 1). Crop residue production differed between crop rotations in each year, except in 2000. For example, crop residue, averaged across tillage systems, was significantly higher in W–F in 2001 and in CW in 2002 than in other crop rotations. Similarly, residue production was higher in CW than in W–L in 2003. Residue production was lower in 2001 then in 2000, 2002, and 2003. This difference may have been due to 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). While greater residue production in CW than in W–F and W–W–F in 2002 could have been attributed to increased cropping intensity in a relatively moist period, greater residue production in W–F in 2001 could have been due to increased soil moisture conservation following fallow in a drier period. Total rainfall during the growing season from April to August, 1999 to 2003, ranged from 83 to 220 mm (Table 2). The monthly 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-year average (Table 2). As a result, crop residue production was higher in 2002 and lower in 2001 than in other years, except in 1998 and 1999 when residue production had to be predicted from grain yield and the average crop residue/grain yield ratio from 2000 to 2003. Since the values in 1998 and 1999 were much larger than those obtained from 2000 to 2003, it may be possible that residue production in 1998 and 1999 were overestimated. Biomass of plants in CRP was measured only in 2003. Tillage did not influence residue production of crop.

Crop rotation also significantly influenced mean annualized crop residue production from 1998 to 2003 and from 2000 to 2003 (Table 1). Annualized residue production, averaged across tillage and years from 1998
to 2003, was greater in W–F than in W–L and W–W–F. When residue from 1998 and 1999 was excluded, annualized residue production was greater in CW than in other rotations, except in W–F. This indicates that the amount of crop residue returned to the soil either increased with increasing cropping intensity, as reported by others (Halvorson et al., 2002a; Ortega et al., 2002; Sherrod et al., 2003), or soil water conservation following fallow (Farhani et al., 1998; Halvorson et al., 2002a) probably increased residue production of spring wheat in W–F.

3.2. Soil carbon fractions

The SOC and PCM at the 0–5, 5–20, and 0–20 cm depths were not influenced by tillage, crop rotation, and their interaction. Averaged across treatments, SOC was 5.8, 14.7, and 20.5 Mg ha\(^{-1}\) and PCM was 55, 156, and 211 kg ha\(^{-1}\) at 0–5, 5–20, and 0–20 cm, respectively, with coefficient of variation ranging from 10 to 45%. Although concentrations (g kg\(^{-1}\)) of SOC and PCM were higher at the 0–5 than at 5–20 cm depth, increased thickness of soil layer increased SOC and PCM contents (Mg ha\(^{-1}\) or kg ha\(^{-1}\)) at 5–20 cm compared with 0–5 cm. Increased amount of crop residue returned to the soil with increasing cropping intensity (Table 1) or increased soil moisture conservation following fallow did not influence SOC and PCM. In the semiarid dryland region of the central Great Plains, USA, Sherrod et al. (2003, 2005) reported that an increase in

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Effects of tillage and crop rotation on crop residue production (Mg ha(^{-1})) from 1998 to 2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tillage(^d)</td>
<td></td>
</tr>
<tr>
<td>CT</td>
<td>4.05(^e)</td>
</tr>
<tr>
<td>NT</td>
<td>4.31a</td>
</tr>
<tr>
<td>Crop rotation(^f)</td>
<td></td>
</tr>
<tr>
<td>CW</td>
<td>5.55</td>
</tr>
<tr>
<td>W–F</td>
<td>2.82</td>
</tr>
<tr>
<td>W–L</td>
<td>5.39</td>
</tr>
<tr>
<td>W–W–F</td>
<td>3.64</td>
</tr>
<tr>
<td>W–P–F</td>
<td>3.52</td>
</tr>
<tr>
<td>LSD (0.05)(^g)</td>
<td>0.82</td>
</tr>
<tr>
<td>SPCP (^h)</td>
<td>–</td>
</tr>
<tr>
<td>Significance(^i)</td>
<td>Tillage (T)</td>
</tr>
<tr>
<td>Crop rotation (C)</td>
<td>***</td>
</tr>
<tr>
<td>T × C</td>
<td>NS</td>
</tr>
</tbody>
</table>

\(^a\) Crop residue yield for 1998 and 1999 were projected from their grain yield and the average biomass yield: grain yield ratio from 2000 to 2003.
\(^b\) Mean annualized crop residue yield from 1998 to 2003.
\(^c\) Mean annualized crop residue yield from 2000 to 2003.
\(^d\) Tillage is CT, conventional till; NT, no-till.
\(^e\) Numbers followed by same letters within a tillage treatment are not significantly different at \(P \leq 0.05\) by the least square means test.
\(^g\) Least significant difference between treatments at \(P = 0.05\).
\(^h\) Values for CRP (conservation reserve program containing alfalfa and grasses) are shown for comparison only and not used in the statistical analysis of data.
\(^i\) Significance levels: * \(P \leq 0.05\); ** \(P \leq 0.01\); *** \(P \leq 0.001\); NS, not significant.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Mean monthly air temperature and total monthly rainfall during the growing season from April to August 1999 to 2003 near the experimental site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Month</td>
<td>1999</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td></td>
</tr>
<tr>
<td>April</td>
<td>3.0</td>
</tr>
<tr>
<td>May</td>
<td>10.0</td>
</tr>
<tr>
<td>June</td>
<td>16.7</td>
</tr>
<tr>
<td>July</td>
<td>17.8</td>
</tr>
<tr>
<td>August</td>
<td>20.0</td>
</tr>
<tr>
<td>Rainfall (mm)</td>
<td></td>
</tr>
<tr>
<td>April</td>
<td>10</td>
</tr>
<tr>
<td>May</td>
<td>30</td>
</tr>
<tr>
<td>June</td>
<td>40</td>
</tr>
<tr>
<td>July</td>
<td>43</td>
</tr>
<tr>
<td>August</td>
<td>35</td>
</tr>
<tr>
<td>Total</td>
<td>158</td>
</tr>
</tbody>
</table>
SOC and active soil C with increasing cropping intensity in NT only occurred with 12 years of NT management. Similarly, various researchers (Franzluebbers et al., 1994, 1995; Schomberg and Jones, 1999; Doyle et al., 2004) have found significant effects of tillage and crop rotations on active and passive fractions of soil C after 9–58 years of study. Probably, longer time than the present 6 years of study may be needed to obtain significant impact of treatments on SOC and PCM in the drylands of the northern Great Plains, although there was an increased trend of SOC with crop rotations in NT (6.4 Mg ha\(^{-1}\)) compared with CT (5.2 Mg ha\(^{-1}\)) at 0–5 cm (\(P \leq 0.10\)).

In contrast to SOC and PCM, crop rotation significantly influenced MBC at the 0–5 cm depth, in which MBC was higher in W–W–F than in W–F (Fig. 1). Despite the higher amount of crop residue returned to the soil in W–F than in W–W–F (Table 1), increasing cropping intensity increased MBC in W–W–F compared with W–F. Sherrod et al. (2005) reported a similar increase in MBC with increasing cropping intensity in NT. Although MBC is correlated with plant C input (Sherrod et al., 2005), greater MBC with increased availability of fresh residue with reduction in the length of fallow period has also been observed (Campbell et al., 1992; Schomberg and Jones, 1999). As expected, active C fractions, such as MBC, can be an effective response variable to changes in soil and crop management practices even when changes in SOC are not detectable.

The proportion of SOC as PCM and MBC was neither influenced by tillage, crop rotation, nor their interaction. Among treatments, PCM accounted for 0.8–1.2% and MBC for 4.8–8.5% of SOC. These values were lower than the reported range of 2.0–2.9% for SOC as PCM (Sainju et al., 2002, 2003) and below or within the range of 6.0–8.7% for SOC as MBC (Sainju et al., 2002, 2003; Sherrod et al., 2005). The PCM/MBC ratio, i.e., the proportion of CO\(_2\) respired by microorganisms, at 5–20 and 0–20 cm was, however, influenced by the interaction of tillage and crop rotation, and was higher in NT with W–F than in other treatments (Table 3). This indicates that increased residue accumulation at the soil surface along with greater length of fallow period probably increased soil water content, which may have increased microbial activities relative to microbial biomass in NT with W–F system.

### Table 3

<table>
<thead>
<tr>
<th>Tillage</th>
<th>Crop rotation</th>
<th>PCM/MBC ratio (g kg(^{-1}) MBC) at soil depth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0–5</td>
</tr>
<tr>
<td>CT</td>
<td>CW</td>
<td>177</td>
</tr>
<tr>
<td></td>
<td>W–F</td>
<td>155</td>
</tr>
<tr>
<td></td>
<td>W–L</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td>W–W–F</td>
<td>170</td>
</tr>
<tr>
<td></td>
<td>W–P–F</td>
<td>152</td>
</tr>
<tr>
<td>NT</td>
<td>CW</td>
<td>121</td>
</tr>
<tr>
<td></td>
<td>W–F</td>
<td>230</td>
</tr>
<tr>
<td></td>
<td>W–L</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>W–W–F</td>
<td>135</td>
</tr>
<tr>
<td></td>
<td>W–P–F</td>
<td>160</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td></td>
<td>–</td>
</tr>
<tr>
<td>CT(^a)</td>
<td>CRI(^d)</td>
<td>158</td>
</tr>
<tr>
<td>NT(^a)</td>
<td>CRI(^d)</td>
<td>117</td>
</tr>
</tbody>
</table>

**Significance**
- **Tillage (T)** NS NS NS
- **Crop rotation (C)** NS NS NS
- **T × C** NS

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\(^{a}\) Tillage is CT, conventional till; NT, no-till.
\(^{c}\) Least significant difference between treatments at \(P = 0.05\).
\(^{d}\) Values for CT-CRP (conservation reserve program containing alfalfa and grasses) and NT-CRP are shown for comparison only and not used in the statistical analysis of data.
\(^{e}\) Significance levels: *\(P \leq 0.05\); NS, not significant.
3.3. Soil nitrogen fractions

Significant tillage × crop rotation interaction occurred for STN at 5–20 cm, PNM at 0–5 cm, and MBN at 0–5 and 0–20 cm (Table 4). The STN at 5–20 cm was greater in CT with W–L than in other treatments, except in NT with W–W–F. The PNM at 0–5 cm was greater in CT with W–L and W–P–F than in other treatments, except in NT with W–W–F. Similarly, MBN at 0–5 cm was greater in CT with W–L than in other treatments, except in CT with W–F and W–P–F. At 0–20 cm, MBN was greater in CT with CW than in CT with W–L and NT with W–F. As with C fractions, the coefficient of variation for N fractions was relatively high at 8–38%.

The increased STN, PNM, and MBN in CT with W–L and W–P–F could be attributed to inclusion of legume crops, such as lentil and pea, in the crop rotation, which supplied greater amount of N due to their higher N concentration and more rapid decomposition as well as incorporation of residue to a greater depth in the soil with tillage. Legumes, because of higher N concentration and lower C/N ratio, decompose rapidly in the soil and supply greater amount of N than nonlegumes (Kuo et al., 1997, Sainju et al., 2002). Nitrogen mineralization can be increased with inclusion of legume crops in the rotation (Carpenter-Boggs et al., 2000). As a result, the rate of N fertilization required for optimal production of succeeding crops can be reduced (Heichel and Barnes, 1984; Franzluebbers et al., 1994, 1995). Conservation of N in MBN and STN would reduce losses of mineral N to the atmosphere and groundwater (Wood et al., 1991).

As legume residues decompose in soil, an increase in active N fractions may take place, but increased sequestration of N through increase in STN may be short-lived, because an increase in soil organic N has been reported to be closely associated with increased SOC, regardless of management practices (Kuo et al., 1997; Sainju et al., 2002). A trend for greater STN and SOC at 0–5 cm in NT with CW and W–W–F occurred compared with other treatments (P ≤ 0.10). This trend suggested that SOC and STN increased with reduced tillage and increased cropping intensity, as reported previously (Halvorson et al., 2002a,b; Sherrod et al., 2003). With lower amount of annualized crop residue

### Table 4

Effects of tillage and crop rotation on soil total N (STN), potential N mineralization (PNM), and microbial biomass N (MBN) contents at the 0–20 cm depth in 2004

<table>
<thead>
<tr>
<th>Tillage</th>
<th>Crop rotation</th>
<th>STN content (Mg ha(^{-1})) at soil depth</th>
<th>PNM content (kg ha(^{-1})) at soil depth</th>
<th>MBN content (kg ha(^{-1})) at soil depth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0–5 cm</td>
<td>5–20 cm</td>
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<td>CRP(^d)</td>
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<td>CRP(^d)</td>
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<td>1.70</td>
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</table>

Significance

- **Tillage** (T)
  - NS
- **Crop rotation (C)**
  - NS
- **T × C**
  - NS

\(^a\) Tillage is CT, conventional till; NT, no-till.
\(^c\) Least significant difference between treatments at \(P = 0.05\).
\(^d\) Values for CT-CRP (conservation reserve program containing alfalfa and grasses) and NT-CRP are shown for comparison only and not used in the statistical analysis of data.
\(^e\) Significance levels: \(^*\) \(P \leq 0.05\); NS, not significant.
returned to the soil (1.4–2.0 Mg ha\(^{-1}\) yr\(^{-1}\)) compared with 2.2–3.2 Mg ha\(^{-1}\) yr\(^{-1}\) in the central Great Plains (Halvorson et al., 2002a; Sherrod et al., 2003), it would likely take more than the 6 years of this study to detect significant impact of tillage and crop rotation on SOC and STN.

The surface increase in active N fractions with the inclusion of legumes in the crop rotation did not occur in subsurface soil. However, MBN at 0–20 cm was higher in CT with CW than in other treatments, except in CT with W–F and W–W–F and NT with CW (Table 4). Increased amount of crop residue returned to the soil with increasing cropping intensity (Table 1) along with incorporation to a greater depth in soil with tillage likely increased N immobilization and MBN in CT with CW at 0–20 cm.

Because PNM and MBN were different between treatments at the surface soil (Table 4), the proportion of STN as PNM and MBN were also influenced by tillage, crop rotation, and their interaction at the 0–5 cm depth (Table 5). The PNM/STN ratio at 0–5 cm was higher in CT with W–L and W–P–F than in other treatments, except in CT with W–F and NT with W–W–F. Similarly, MBN/STN ratio at 0–5 cm was higher in CT with W–L than in NT with CW, W–F, and W–P–F. The presence of legumes in the crop rotation clearly increased PNM and MBN contents relative to STN when residues were incorporated into the soil using tillage. The results showed that active N fractions, such as PNM and MBN, were sensitive response variables to tillage and crop rotation compared with STN. Unlike PCM/MBC ratio, the PNM/MBN ratio was not influenced by treatments and averaged 212 g kg\(^{-1}\) MBN at the 0–20 cm depth.

Soil NH\(_4\)-N content was not influenced by tillage and crop rotation. In contrast, tillage, crop rotation, and tillage × crop rotation interaction significantly affected NO\(_3\)-N content at the 5–20 cm depth (Table 5). The NO\(_3\)-N content at 5–20 cm was greater in CT with W–L than in other treatments. In NT, NO\(_3\)-N content was higher in CW than in other crop rotations. As with other N fractions, legumes in the crop rotation increased NO\(_3\)-N when the residue was incorporated into the soil with tillage. When residue was placed at the soil surface with NT, NO\(_3\)-N content increased with increasing cropping intensity in CW

<table>
<thead>
<tr>
<th>Tillage</th>
<th>Crop rotation</th>
<th>PNM/STN ratio (g kg(^{-1}) STN) at soil depth</th>
<th>MBN/STN ratio (g kg(^{-1}) STN) at soil depth</th>
<th>NO(_3)-N content (kg ha(^{-1})) at soil depth</th>
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<tr>
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<td>0–5 cm</td>
<td>5–20 cm</td>
<td>0–20 cm</td>
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<td>CT</td>
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<td>5.5</td>
<td>4.8</td>
</tr>
</tbody>
</table>

Significance:

- **P < 0.05**
- NS: not significant

\* Tillage is CT, conventional till; NT, no-till.
\* Least significant difference between treatments at \(P = 0.05\).
\* Values for CT-CRP (conservation reserve program containing alfalfa and grasses) and NT-CRP are shown for comparison only and not used in the statistical analysis of data.
intensity. A possible explanation for this may be the result of lower efficiency of crops to remove N from the soil during continuous cropping and N fertilization in NT, thereby resulting in higher residual N build up after crop harvest.

3.4. Comparison of soil carbon and nitrogen fractions in croplands and CRP

Inclusion of continued CRP planting as a treatment similar in nature to grasslands allowed us to compare soil C and N levels under croplands and CRP planting. Soil C and N fractions in the CRP under CT, where alfalfa and grasses were planted by cultivating the soil, tended to be slightly lower than under NT (Tables 3–5, Fig. 1). The average SOC, PCM, and MBC at the 0–20 cm depth across the treatments in croplands were 97, 95, and 88%, respectively, of those found in the average of CRP planting in CT and NT. The MBC at 0–5 cm in W–W–F was 95% of that in CRP (Fig. 1). The average PCM/MBC ratio at 0–20 cm was 107% of that in CRP (Table 3). The STN and NO₃-N at 5–20 cm and PNM and MBN and 0–5 cm in CT with W–L were 138, 364, 705, and 178%, respectively, of those found in CRP planting, indicating N benefits by including legumes in the crop rotation in croplands, although CRP contained grasses mixed with alfalfa which can fix N from the atmosphere. As a result, PNM/STN and MBN/STN ratios at 0–5 cm were also higher in CT with W–L than those in CRP. At 0–20 cm, average STN, PNM, MBN, NH₄-N, and NO₃-N across the treatments in croplands were 100, 127, 100, 44, and 165%, respectively, of those in CRP. These data suggest that 6 years of tillage and cropping in land previously under CRP planting reduced total SOC and active C fractions by 3–12% but maintained or enriched N fractions compared with continued CRP planting. The low annual rainfall (normal 305 mm) and cold winter in the semiarid region of the northern Great Plains probably reduced mineralization of soil organic matter compared with wetter and warmer regions. As a result, soil N fractions could be maintained or enhanced when legumes are introduced in the crop rotation.

4. Conclusions

Tillage and crop rotation influenced the quality, quantity, and placement of crop residues in soil, their rate of mineralization, and soil C and N levels in this semiarid dryland region of the northern Great Plains, USA. Although limited rainfall and a shorter growing season reduced the annualized amount of crop residue returned to the soil compared with the central Great Plain region, active soil C fractions increased with reduced frequency of fallow in the crop rotation. Similarly, inclusion of legumes, such as pea and lentil, in the crop rotation increased soil N fractions when residues were incorporated into the soil to a greater depth using CT. Although 6 years of tillage and crop rotation was too short to observe significant differences in SOC and STN storage, active soil C and N fractions did respond to management practices.

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References


