Microbial biomass and \( N \) cycling under native prairie, conservation reserve and no-tillage in Palouse soils

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**A B S T R A C T**

Tillage management practices that improve soil quality are needed to maintain agricultural productivity. Soil quality can be improved through increases in microbial biomass carbon (MBC) and the nitrogen (N) contents in different pools of soil organic matter (SOM). The objective of our experiment was to study the dynamics of MBC and N cycling in soils collected from the Palouse area of eastern Washington State. Soil managements were: no tillage for 4 (NT4) and 28 (NT28) years, conservation reserve program (CRP), native prairie (NP), and conventional tillage (CT). Microbial biomass carbon was 50% less in the CT soil than the NP soil and there was 74% less total soil N (TSN) in the surface CT soil compared to the NP soil. Conversion of CT to CRP, NT4, and NT28 increased MBC in the 0–5 cm depth by 40, 6, and 78%, respectively. Compared to CT, the TSN content was 20, 57, and 94% higher in CRP, NT4 and NT28, respectively. The net \( N \) mineralized (Nmin) over 180 days in the surface 5 cm was highest (69.5 µg N/cm\(^3\)) in NT28 soil and lowest (14.2 µg/cm\(^3\)) in CRP. Interestingly, the CT soil mineralized as much \( N \) as the NT systems but had less TSN than NT. Compared to NP, CT had a 70% reduction in particulate organic matter nitrogen (POM-N) to a depth of 20 cm. The conversion of CT soil to CRP, NT28, and NT4 enhanced the POM-N content by 65, 216, and 101% at 0–5 cm. The proportion of POM-N to TSN was lowest in CT soil whereas the NT and CRP soils were considerably higher. The lower Nmin/MBC ratios (qN) of the conservation systems imply a higher immobilization capacity and tighter soil \( N \) cycling. Mineralized \( N \) per unit of respiration (Nmin/CO\(_2\)-C) was highest in CT and NT28 management systems suggesting different factors were responsible in these systems for exhibiting almost similar values. The Nmin ratios along with MBC and POM-C relationships could be useful soil quality indicators in judging tillage-induced changes in soil management systems.

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1. Introduction

Carbon (C) is an indispensable necessity for soil fertility; it is strongly correlated with nitrogen (N) and fuels the microbial engine that drives the nitrogen cycle (Korschens, 1998). There is considerable interest in the concept of soil quality as it relates to the use of agricultural lands in sustainable production including \( N \) management (Doran and Parkin, 1994; Salinas-Garcia et al., 1997). For example microbial biomass is a sensitive indicator of \( N \) fertilizer management affects on soil quality (Rice et al., 1986; McCarty and Meisinger, 1997; Staben et al., 1997; McCarty et al., 1998). In addition to microbial biomass carbon (MBC), N mineralization (Nmin) and ratios such as Nmin/MBC (qN) and Nmin/CO\(_2\)-C evolved respond readily to changes in soil management and can provide an effective early warning of deterioration of soil quality (Smith, 1994, 2002).

This loss is most rapid during the first few years of cultivation, and eventually an apparent equilibrium is established, provided constant management practices are employed. It has been well documented that tillage has reduced soil organic matter (SOM) stocks. Between 35 and 50% of the SOM and N were lost during the first 50 years of tillage in the Great Plains of the United States (Bauer and Black, 1981). Over a 14-year period in Canada, cultivated, prairie soils lost 26% of native SOM and 33% of native N. In the next 20 years, losses decreased by half (Doughty et al., 1954; Campbell et al., 1975). In other Canadian soils, over a 60–80-year period, C and N losses ranged from 50 to 60% and 40 to 60%, respectively (Campbell et al., 1976; Voroney et al., 1981). Furthermore, in Queensland Australia, annual tillage caused a loss of 36% of the soil C and N over a 20–70 year period (Dalal and Mayer, 1986). The long-term effect of tillage is to decrease the SOM level, which, in turn, disrupts nutrient cycling and fertility and degrades soil quality.

Reduced tillage increases the standing stock of macroaggregate-protected soil organic C compared with conventional tillage (CT)

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mostly at the soil surface (Campbell et al., 1995; Franzluebbers and Arshad, 1997). In a 23-year field study, Dolan et al. (2006) found that no-tillage managed soil had >30% more soil organic C (SOC) and soil organic N (SON) than the moldboard plow and chisel plow soils. McCarty et al. (1998) showed that a soil profile typical of plow tillage management can transform to a soil profile characteristic of no tillage (NT) within a 3-year period of transition. In this time period, stratification of organic matter in the profile progressed significantly toward that which occurs after 20 yr of no tillage. A similar pattern was reported by several workers (Carter and Rennie, 1982; Burle et al., 1997; Salinas-Garcia et al., 1997; Kandler et al., 1999; Bayer et al., 2000), who also identified increased accumulation of C and N with greater periods of no-till management.

Microbial biomass C (MBC) is also stratified under no-tillage compared to being homogeneous in the 0– to 15-cm layer under plow tillage (Alvarez, 1998). With the transition to no-tillage, MBC, microbial biomass N, and active N pools were shown to increase more rapidly in the upper soil profile than did the total pools of SOC and SON (McCarty et al., 1998; Woods, 1989). Doran (1987) reported that microbial biomass and potentially mineralizable nitrogen in the 0–7.5 cm surface layer of no till soils were 34% higher than those of ploughed soils, although the opposite was true at 7.5–15-cm depth. Wright et al. (2005) found MBC to be greatest under no-till management but only in the surface 2.5 cm with little tillage effect to 20 cm.

The importance of reduced tillage in N cycling and soil quality may be dependent upon the length of time the soil has been subject to change in management. In this study, we assessed the magnitude of change of a Palouse silt loam soil from pre-cultivation native prairie conditions with respect to total soil C (TSC), total soil N (TSN), particulate organic matter C (POM-C), particulate organic matter N (POM-N), microbial biomass C (MBC), and microbial biomass N, as well as soil physical properties. In this study, we assessed the importance of different factors influencing MBC and its activity.

### 2. Materials and methods

#### 2.1. Soil sampling

Five fields with differing management history, but the same soil classification and landscape position, were identified to represent diverse land uses in the Palouse region of eastern Washington State, near the city of Pullman. The climate type of this zone is Mediterranean with an annual precipitation averaging 544 mm and mean annual air temperature of 8.3 °C. Historically, conversion of NP to agricultural uses in the Palouse region occurred in the late 1800s, was dependent on inversion tillage using a moldboard plow and resulted in annual soil erosion rates exceeding 25 Mt ha⁻¹ (USDA, 1978). The sites were located in summit positions (0 to 3% slope) on Palouse silt loam soils (fine-silty, mixed, superactive, mesic pachic ultic Haploxerolls, Palouse series), where the influence of soil deposition from historic erosion processes would be minimized. All soils had a similar soil texture, with particle size distribution of 21% sand, 59% silt and 20% clay. Management, vegetation and site descriptions for each location are given in Table 1.

<table>
<thead>
<tr>
<th>Site description</th>
<th>Location*</th>
<th>Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native Prairie (NP)</td>
<td>Kramer Palouse Natural Area (KPNA) near Colton</td>
<td>Never cultivated, Idaho fescue, blue bunch, wheat grass, June grass grows naturally</td>
</tr>
<tr>
<td>Conservation Reserve Program (CRP) 28 year no tillage (NT28)</td>
<td>Grower Field near Albion Grower Field, near Palouse</td>
<td>Smooth brome grass grows for 11 years, no fertilization or cultivation</td>
</tr>
<tr>
<td>4 year no tillage (NT4)</td>
<td>Palouse Conservation Field Station, Pullman</td>
<td>Winter wheat-spring barley/spring grain legume (pea or lentil), seeds was accomplished directly into the preceding years crop residue by means of a coulter-type planter</td>
</tr>
<tr>
<td>Conventional tillage (CT)</td>
<td>Grower Field, adjacent to KPNA near Colton</td>
<td>Winter wheat-spring barley/spelt seed, seeding was accomplished directly into the preceding years crop residue by means of a coulter-type planter</td>
</tr>
<tr>
<td>* All the management practices are situated in Washington State, USA.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Soil samples consisted of forty soil cores (4 cm diameter) from each location in depth increments of 0– to 5-, 5– to 10- and 10– to 20-cm were collected using a 4 cm diameter hammer driven soil core sampler. Immediately after collection, soil samples were brought to the laboratory in a cooler and stored at 4 °C. Four intact soil samples from each location for a C mineralization study and 27 cores (3 intact cores with 9 sampling days) were used for MBC and N mineralization study (Section 2.3). An additional 5 cores were taken for the determination of water content, field capacity and bulk density. Soil moisture content was determined after drying at 105 °C for 24 h. Soil samples from rest of the 4 cores per treatment were air dried, ground, and sieved through a 2-mm sieve for analyses of total soil C (TSC) total soil N (TSN), particulate organic matter C (POM-C) and particulate organic matter N (POM-N).

Soil bulk density was calculated from weights of field-moist soil, the oven-dried sub-sample and the volume of the core sampler following the method of Veihmeyer and Hendrickson (1948).

#### 2.2. Soil microbial biomass, C and N mineralization

Soil MBC and N mineralization were measured by destructive sampling a set of soil cores after 0, 5, 10, 20, 40, 60, 100, 140, 180 days of initial incubation. Soil cores collected from the 0– to 5-, 5– to 10-, and 10– to 20-cm depths at each site were moistened to field capacity (25% water by weight, ~0.033 MPa) and placed in a 500-ml canning jar and a vial of water to maintain high humidity, and incubated for 26 wk at room temperature (20 °C). On each sampling date 3 soil cores from each site were passed through 2-mm sieve. Soil microbial biomass was measured by the substrate induced respiration (SIR) method (Anderson and Domsch, 1978; Smith et al., 1985) in which 0.5 ml of a 12 g glucose/L solution was added to moist soil equivalent to 10 g of oven dry soil and incubated for 3 h at 22 °C. Vials were covered for 2h, flushed with moist air, septa capped and CO₂ in the head space measured by a gas chromatograph (Schimadzu GC 17-A) after 1 h incubation. The MBC was estimated by using the equation of Anderson and Domsch (1978):

\[ x = 40.04y + 0.37 \]  

Where

- \( x \) mg microbial biomass carbon 100 g soil⁻¹
- \( y \) ml CO₂ 100 g soil⁻¹ h⁻¹

Soil from the harvested cores was also used to determine NH₄–N and NO₃–N over the 180 day incubation. The NH₄–N and NO₃–N in a
5 g soil sub-sample was extracted with 2 M potassium chloride (KCl) at a soil solution ratio of 1:5. KCl extracts were refrigerated at 4 °C and subsequently analyzed for NH₄–N and NO₃–N (Net N mineralization) colorimetrically on a continuous rapid flow analyzer (Alpkem RFA-301).

Soil C mineralization was studied from four intact cores (preserved at 4 °C) collected from the 0– to 5-, 5– to 10-, and 10– to 20-cm depths at each site. Soil cores were moistened to field capacity (25% water by weight, −0.033 MPa) and placed in a 500-mL canning jar with a vial containing 5 mL of 1 mol L⁻¹ NaOH to trap evolved CO₂ and a vial of water to maintain high humidity, and incubated for 26 wk at room temperature (20 °C). During the initial 2 wk, the NaOH trap was replaced at half-week intervals and subsequently at weekly intervals through 26 wk. Control jars lacking a soil core were incubated in the same manner. The jars, including controls, were vented to the atmosphere during replacement of the NaOH trap. The quantity of CO₂–C evolved was determined by titration with 1 mol L⁻¹ HCl using phenolphthalein as an indicator (Anderson, 1982). Amounts of respired CO₂ were calculated as milligrams CO₂–C per cubic centimeter and cumulative CO₂–C evolution was calculated over 26 wk.

### 2.3. Total soil total C (TSC), total soil N (TSN), particulate organic matter C (POM-C) and particulate organic matter N (POM-N)

Total C, N, POM-C and -N in soil were determined at the start of the experiment. For total soil C and N concentrations a soil sub-sample was air dried, ground and determined by dry combustion using a Leco CNS 2000 carbon analyzer (Tabatabai and Brenner, 1970). As the soils used in the present study did not have inorganic C, TSC was considered as soil organic C (SOC). For the determination of POM-C and -N fractions, soil sub-samples were air dried, mixed with 30 ml of 0.5% sodium hexametaphosphate, shaken for 24 h, and poured onto a 53 µm sieve. The solids were rinsed through the sieve with minimal amounts of water and the portions retained on and passed through the sieve were collected separately in pre-weighed plastic boats. Boats due to non disturbance of the soil. In contrast, the MBC in the CT soil decreased because of low labile organic C which continuously declined due to cultivation over 100 years (Purakayastha et al., 2008). Similar increases in MBC and N have been observed in tropical cropping systems (Franchini et al., 2007) and long-term cropping sequences (Wright et al., 2005) where tillage management had the highest impact.

As was expected, there was a significant decline of MBC with soil depth (Table 2). The MBC in CT did not vary widely at different depths which may be due to a more uniform distribution of organic C in the plow layer resulting from physical disturbance in the CT system (Carter and Rennie, 1982). In contrast, there was a significant stratification of MBC from the 0–5 cm to 5–20 cm depth in CRP and NT soils, with the lower depths being similar. The CT soil had significantly more MBC than NT4, NT28 and CRP in the 5–10 cm depth but similar amounts in the 10–20 cm depth which may have been due to soil mixing during repeated tillage under cropping. Previous reports in NT systems have observed the stratification of residue near the soil surface and the increased surface distribution of organic matter and MBC (Holland and Coleman 1987; Dalal et al., 1991, Madejon et al., 2007). In the same climate and soil, Granatstein et al. (1987) also reported that microbial biomass, total C and total N were highest under no-till surface soils (0–5 cm) of Palouse, WA with minimal differences for tillage or depth below 5 cm. However, in a hot humid sub-tropical soil of Texas, Wright et al. (2005) found an increase of MBC and mineralizable N in the surface soil with corn and cotton cropping sequences for twenty years under no-till and minimum tillage systems but little change in MBC concentration in the 2.5 to 20 cm depth.

The dynamics of MBC over 180 day period revealed that the MBC increased from the initial amount and peaked somewhere between 5 to 20 days depending upon management and depth (Table 2). The

### Table 2

<table>
<thead>
<tr>
<th>Tillage management</th>
<th>Microbial biomass C</th>
<th>Net N mineralized</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg cm⁻³</td>
<td>µg cm⁻³</td>
</tr>
<tr>
<td>Initial</td>
<td>Maximum</td>
<td>180 day</td>
</tr>
<tr>
<td>0–5 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP</td>
<td>2.56⁴</td>
<td>2.97⁴</td>
</tr>
<tr>
<td>CRP</td>
<td>1.78b</td>
<td>2.41</td>
</tr>
<tr>
<td>NT28</td>
<td>2.26a</td>
<td>2.85</td>
</tr>
<tr>
<td>NT4</td>
<td>1.34c</td>
<td>2.26</td>
</tr>
<tr>
<td>CT</td>
<td>1.27c</td>
<td>2.51</td>
</tr>
<tr>
<td>5–10 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP</td>
<td>1.90a</td>
<td>2.66</td>
</tr>
<tr>
<td>CRP</td>
<td>0.79c</td>
<td>0.91</td>
</tr>
<tr>
<td>NT28</td>
<td>0.72c</td>
<td>0.89</td>
</tr>
<tr>
<td>NT4</td>
<td>0.88c</td>
<td>1.05</td>
</tr>
<tr>
<td>CT</td>
<td>1.26b</td>
<td>1.36</td>
</tr>
<tr>
<td>10–20 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP</td>
<td>1.82a</td>
<td>2.18</td>
</tr>
<tr>
<td>CRP</td>
<td>0.83b</td>
<td>0.84</td>
</tr>
<tr>
<td>NT28</td>
<td>0.78b</td>
<td>0.78</td>
</tr>
<tr>
<td>NT4</td>
<td>0.74b</td>
<td>0.74</td>
</tr>
<tr>
<td>CT</td>
<td>0.76b</td>
<td>1.11</td>
</tr>
</tbody>
</table>

*Significant management differences for each parameter in a particular soil depth are indicated by different letters (P < 0.05) using Duncan’s multiple range test.

Maximum values may have occurred on different days, statistics are not appropriate.

### 3. Results and discussion

#### 3.1. Microbial biomass carbon (MBC)

Microbial biomass C has been advanced as a sensitive biological indicator because it is strongly influenced by management practices and system perturbations (Smith and Elliot, 1990). In the surface (0–5 cm) soil depth, MBC for NP and NT28 sites were greater than the other management sites (Table 2); however, only NP maintained larger amounts of MBC in subsurface soils. The CT soil, being cultivated over 100 years, had 50% less MBC than NP in the surface 5 cm. Compared to the CT soil, the adoption of no tillage and conservation reserve programme increased the MBC in the surface 5 cm by 78, 40, 6% in NT28, CRP and NT4, respectively. The greater MBC in the NP soil can be explained by the larger accumulation of labile organic C over time due to non disturbance of the soil. In contrast, the MBC in the CT soil decreased because of low labile organic C which continuously declined due to cultivation over 100 years (Purakayastha et al., 2008). Similar increases in MBC and N have been observed in tropical cropping systems (Franchini et al., 2007) and long-term cropping sequences (Wright et al., 2005) where tillage management had the highest impact.

As was expected, there was a significant decline of MBC with soil depth (Table 2). The MBC in CT did not vary widely at different depths which may be due to a more uniform distribution of organic C in the plow layer resulting from physical disturbance in the CT system (Carter and Rennie, 1982). In contrast, there was a significant stratification of MBC from the 0–5 cm to 5–20 cm depth in CRP and NT soils, with the lower depths being similar. The CT soil had significantly more MBC than NT4, NT28 and CRP in the 5–10 cm depth but similar amounts in the 10–20 cm depth which may have been due to soil mixing during repeated tillage under cropping. Previous reports in NT systems have observed the stratification of residue near the soil surface and the increased surface distribution of organic matter and MBC (Holland and Coleman 1987; Dalal et al., 1991, Madejon et al., 2007). In the same climate and soil, Granatstein et al. (1987) also reported that microbial biomass, total C and total N were highest under no-till surface soils (0–5 cm) of Palouse, WA with minimal differences for tillage or depth below 5 cm. However, in a hot humid sub-tropical soil of Texas, Wright et al. (2005) found an increase of MBC and mineralizable N in the surface soil with corn and cotton cropping sequences for twenty years under no-till and minimum tillage systems but little change in MBC concentration in the 2.5 to 20 cm depth.

The dynamics of MBC over 180 day period revealed that the MBC increased from the initial amount and peaked somewhere between 5 to 20 days depending upon management and depth (Table 2). The
MBC then declined over the 180 day incubation period to be generally lower than the initial MBC. This indicates a rapid growth of the microbial biomass initially by utilizing the most easily mineralizable soluble carbon substrates. Thereafter, the microbial growth was reduced due to absence of a labile pool of carbon and presence of only intermediate or more resistant C pools (Staben et al., 1997).

### 3.2. Net nitrogen mineralization (Nmin)

The amount of net N mineralized over 180 day period was generally stratified with depth (Table 2). In all the soil depths, NT28 showed the highest amount of net N mineralization. In the 0–5 cm soil depth, CRP and NT4 showed the lowest N mineralization. CRP and NP soils showed the lowest amount of N mineralization in the 5–10 and 10–20 cm soil depths. On an aerial basis (0–20 cm soil depth) nitrogen mineralization was greatest (69.5 kg ha$^{-1}$) in the NT28 soil and lowest (25.5 kg ha$^{-1}$) in the CRP soil (Table 3). The range in the NT and CT soils (55 to 70 kg ha$^{-1}$) is a typical amount of N mineralized from the Palouse soil on a yearly basis. The enhanced N mineralization in NT28 is partially due to its higher POM-N contents (Table 5) which is consistent with the findings of Scharenbroch et al. (2005) who also reported an enhanced microbial biomass N (71%), potential C mineralization (20%) and potential N mineralization (83%) in undisturbed older urban Palouse soil (mean landscape age of 64 years). In another study from Canada reported an increased proportion of mineralizable N in the more labile N pools under NT than under CT (Sharifi et al., 2008). The eleven year period without fertilization in the CRP system was not sufficient for the build up of SON and the mineralizable N pool. However, Burke et al. (1995) has shown that cultivated field which was abandoned 50 years ago to short grass steppe in north-east Colorado, USA has recovered much of the active soil organic matter (microbial biomass, potentially mineralizable N) but recovery of the total soil organic matter pool will take a much longer time period. Robles and Burke (1997) reported that grasses grown in CRP soils (80% legume:20% grass mixture) in Wyoming, USA, had the higher rates of potential net N mineralization than the same grasses grown in the more nutrient-depleted CRP fields (20% legume:80% grass mixture). In the present study CT and NT soil mineralized twice as much as the NP and CRP soils probably due to the effects of surface disturbance in their management history and the addition of fertilizer N every year (Smith and Elliot, 1990).

Interestingly, all of the soils exhibited linear N mineralization over the 180 day incubation period (data not shown) which indicates high soil N mineralization potential (Smith et al., 1980). In addition to the lack of trends across managements, the net soil N mineralization was not correlated to either soil TSN or POM-N. Even though conservation management tended to increase SON, Liang et al. (2004) found that depending upon the soil this did not translate directly into an increase in mineralizable N. However, in a Brazilian oxisol there was a consistent increase in biological activity and N mineralization with no-till management (Green et al., 2007).

Net N mineralization is a net balance between SOM mineralization and microbial immobilization which is influenced by the magnitude of the labile C and N pools. The varied response of the N mineralized in each soil during the 180 day incubation is due to the complex interaction of microbial biomass and enzymatic activity with different labile C and N pools in each soil management system (Smith, 1994; Staben et al., 1997). This supports the concept that the complexity of N cycling and the interaction of C and N pools make it difficult to predict the available soil N for plant growth (Smith and Paul, 1990).

### 3.3. Total soil N (TSN) and particulate organic matter N (POM-N)

In general, the TSN contents in the 0–5 cm depth were higher than the 5–10 cm or 10–20 cm depths (Table 4). As compared to lower depths, a greater accumulation of TSN was observed in surface depth due to conversion of CT to NT and CRP. This indicated a stratification of crop residues and organic matter in the surface depth under NT or CRP systems. TSN contents in NP were greater than other management systems at all soil depths, while the lowest values were observed in CT and CRP soils. The long-term no tillage (NT28) had hardly any influence on TSN contents as compared to short-term no tillage (NT4). TSN contents in CT soil, compared to NP soil, have decreased by 74, 51 and 55% in the 0–5, 5–10 and 10–20 cm depths, respectively. On the other hand in the 0–5 cm soil depth, there was an increase in TSN over CT by 20, 94 and 57% in CRP, NT28 and NT4, respectively. As compared to lower depths a greater accumulation of TSN was observed in surface depth due to conversion of CT land to NT and CRP. The stratification of N under NT system has also been reported by several others (Franzluebbers et al., 1995; Alvarez et al., 1998; Mrabet et al., 2001). Fuentes et al. (2004) reported a 64% and 58% reduction in TSN in 0–5 and 5–10 cm soil depths, respectively due to conventional tillage of native prairie soils of eastern Washington. Solomon et al. (2000) showed a 56% reduction in C and 51% reduction in N contents in A horizon of chromic luvisol in Tanzania as a result of clearing and subsequent cultivation of native tropical woodland. Similar decreases in total soil C and N contents in 0–17.5 cm soil depth in Brazil have also been reported (Bayer et al., 2000). In the deeper depths the TSN concentrations in NT increased by 25% (5–10 cm) and 19% (10–20 cm) in comparison to the CT soil. Similar increases with depth have been observed in arid wheat based systems where TSN increased by 38–68% (Dou and Hons, 2006) and in corn-soybean rotations where

#### Table 3

<table>
<thead>
<tr>
<th>Tillage management</th>
<th>TSN (mg ha$^{-1}$)</th>
<th>POM-N (mg ha$^{-1}$)</th>
<th>Net Nmin (kg ha$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NP</td>
<td>6.48a</td>
<td>1.30a</td>
<td>49.3c</td>
</tr>
<tr>
<td>CRP</td>
<td>2.50c</td>
<td>0.39c</td>
<td>25.5d</td>
</tr>
<tr>
<td>NT28</td>
<td>3.57b</td>
<td>0.60b</td>
<td>69.5a</td>
</tr>
<tr>
<td>NT4</td>
<td>3.51b</td>
<td>0.52b</td>
<td>57.9b</td>
</tr>
<tr>
<td>CT</td>
<td>2.63c</td>
<td>0.31c</td>
<td>55.2bc</td>
</tr>
</tbody>
</table>

* Significant management differences for each parameter are indicated by different letters (P=0.05) using Duncan’s multiple range test.

#### Table 4

<table>
<thead>
<tr>
<th>Tillage management</th>
<th>TSN (mg cm$^{-1}$)</th>
<th>POM-N (mg cm$^{-1}$)</th>
<th>POM-N/TSN (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NP</td>
<td>4.93a</td>
<td>1.08a</td>
<td>0.33cd</td>
</tr>
<tr>
<td>CRP</td>
<td>1.55c</td>
<td>0.32d</td>
<td>0.060c</td>
</tr>
<tr>
<td>NT28</td>
<td>2.50b</td>
<td>0.62e</td>
<td>0.16b</td>
</tr>
<tr>
<td>NT4</td>
<td>2.03b</td>
<td>0.40c</td>
<td>0.15b</td>
</tr>
<tr>
<td>CT</td>
<td>1.29c</td>
<td>0.20d</td>
<td>0.14b</td>
</tr>
</tbody>
</table>

* Significant management differences for each parameter in a particular soil depth are indicated by different letters (P=0.05) using Duncan’s multiple range test.
no-tillage increased both SOC and TSN by more than 30% (Dolan et al., 2006). In Wyoming, USA Robles and Burke (1997) reported that the net impacts of increased plant inputs and cessation of tillage in CRP land increased coarse POM-C and -N by factors of two to four relative to wheat-fallow fields, but had negligible effects on total SOM.

Stocks of TSN (0–20 cm) with these agricultural management histories follows the order: NP > NT28 = NT4 > CT = CRP which differs from our original hypothesis (Table 3). Deviations from the hypothesized sequence could possibly be due to differences among the sites in initial levels of TSN prior to management changes and relatively poor biomass production in CRP due to lack of fertilization. Insights of the influence of these factors on TSN can be gained through examining TSN-depth-stratification and measures of labile TSN constituents. The equivalent amount of TSN in NT28 and NT4 is probably due to higher levels of TSN contents in the former than the latter at the initiation of experiment. The reduction of TSN content in CT is primarily due to over 100 years of cultivation of NP.

The POM-N stock in 0–20 cm depth was greatest in NP soil, and lowest in CT and CRP soils (Table 3). Though the no tillage practices for long-term (NT28) did not influence the POM-N stock over short-term no tillage (NT4), conversion of CT to long-term NT (NT28) significantly increased POM-N stock.

The greatest concentrations of POM-N were observed in the NP soil at all soil depths (Table 4). The NP, NT28, NT4 soils were significantly higher in POM-N than in the CT and CRP soils at 0–5 cm but similar by the 10–20 cm depth. Compared to the NP soil, the POM-N in the CT soil decreased by 81, 78 and 71% in the 0–5, 5–10 and 10–20 cm depths, respectively. The adoption of NT increased POM-N in the 0–5 cm depth by 210, and 100% in NT28 and NT4, respectively. At the 10–20 cm depth, CRP, NT28, NT4 and CT treatments did not differ significantly for POM-N concentration. This suggests that at the lower depths recovery of POM-N is very slow. The CRP sites, however, did not achieve the subsurface storage of POM-N found in NT even after four years. This result may have been reversed if burning had been eliminated from bluegrass seed production and the CRP site fertilized in order to promote biomass additions to soil (Huggins et al., 1997). The POM fractions or light fraction organic matter tends to be greater under NT systems (Malhi et al., 2006) and is more sensitive to management practices (Dou and Hons, 2006). Considering all management treatments POM-N was linearly correlated to SON (R² = 0.96, P < 0.01) at all depths.

The ratio of POM-N/TSN was highest in NT28 (along with CRP and NT28) and lowest in CT for the 0–5 cm soil depth (Table 4). But at depth NP and CRP showed higher ratio than the others. In the NP soil 18–22% of the total N was POM-N whereas in the CT soil it accounted for 10 to 15%. The low proportion of POM-N/TSN in CT soil was due to rapid oxidation of POM-N, due to conventional tillage (Paustian et al., 1997). Similarly, Fabrizzi et al. (2003) reported a decreased ratio of POM-N/TSN (14:1) in conventional tillage than in no tillage (20:1) with and without N fertilization at the Balcarce Experimental Station, Argentina. On the contrary, the adoption of NT and CRP dramatically increased the amount of POM-N as a percentage of TSN ranging from 15 to 25% in the surface soil. The greater POM-N/TSN ratio under NT systems reflects the influence of tillage on SOM quality, with a highest proportion of total N present in the active fractions. The build up of a labile N pool with a size of >53 µm can positively impact soil physical structure and aggregation (Fansler et al., 2005) and increase N immobilization and retention (Purakayastha et al., 2008).

3.4. C and N relationships

The short-term no tillage (NT4), long-term no tillage (NT28) and CRP soils showed mostly higher C:N ratio (13–16) of SOM in all the soil depths (Table 5). Contrarily the NP and CT soils had significantly lower C:N ratios ranging from 9 to 11. The C:N ratios of SOM fractions have often been used as indices of quality; however, interpretation of trends can be difficult. Agricultural use of soils reduces total soil C:N ratios, which typically range from 14–8, as labile SOM is lost (Duxbury et al., 1989; Kafka and Koepf, 1989). However, Miller et al. (2004) reported that soil C:N ratio decreased during cultivation only with decreasing temperature. Aggradation of SOM in whole soils is reflected by increasing C:N ratios. However, the mechanisms behind the lower C:N ratios for CT and NP soils are different. The CT soil has reduced C concentrations from oxidation of labile SOM due to tillage (Purakayastha et al., 2008). But fertilizer N inputs to CT soil that results in an apparent low soil C:N ratio, whereas, the NP soil has built up C reserves and has increased the soil N 2 fold thus reducing the soil C:N ratio. The relatively greater TSN in the NP soil is presumably due to more conserved N cycling and high input from native leguminous grasses.

When the ratios of POM-C, N are calculated (Table 5) the NT and CT systems showed similar values to the whole soil C:N ratios, however they decreased with 5–10 cm soil depth for the NT soils and increased with the CT soil. This is a classic example of turning over of residues in a CT system verses a NT system. Higher POM-C:N ratio in NT28 system than in CT system is mainly due to protection of POM inside the soil aggregates which inhibited its decomposition by microbes. Similarly Scharenbroch et al. (2005) reported higher particulate organic matter C:N ratios from less disturbed older urban soils (mean landscape age of 64 years) than more disturbed newer urban soils (mean landscape age of 9 years) in the same Palouse region. No N inputs for the NP and CRP along with uniform stratification of plant biomass make the POM-C:POM-N ratio more uniform with depth. Nevertheless, N limitation in CRP soil likely restricted the decay in the highly rooted smooth brome grass (Malhi et al., 2003a,b). On the contrary, the higher POM-C:N ratio in NP soil reflects the large labile C and N pools in this system (Purakayastha et al., 2008). Thus higher POM-C:N ratio is attributed due to aggradations of SOM.

The Nmin/MBC ratio (qN) can be an indicator of substrate quality and efficiency of N cycling (Smith, 1994). This ratio was higher in CT and NT28 than in the NP, NT4 or CRP systems at 0–5 cm depth (Table 6). Although both the CT and NT28 soils exhibited similar ratios, there might be different factors responsible for the similarity. As

### Table 5

<table>
<thead>
<tr>
<th>Tillage management</th>
<th>TSC/TSN</th>
<th>POM-C/POM-N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil depth, cm</td>
<td></td>
<td>Soil depth, cm</td>
</tr>
<tr>
<td>0–5</td>
<td>10.6b</td>
<td>10.2b</td>
</tr>
<tr>
<td>5–10</td>
<td>15.6a</td>
<td>13.4a</td>
</tr>
<tr>
<td>10–20</td>
<td>14.3a</td>
<td>14.2a</td>
</tr>
<tr>
<td>15–20</td>
<td>11.3b</td>
<td>9.3b</td>
</tr>
</tbody>
</table>

* Significant management differences for each parameter in a particular soil depth are indicated by different letters (P = 0.05) using Duncan’s multiple range test.

### Table 6

<table>
<thead>
<tr>
<th>Tillage management</th>
<th>Nmin/MBC × 10^2</th>
<th>Nmin/CO2 × C × 10^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil depth, cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5–10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10–20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NP</td>
<td>1.3b</td>
<td>0.8c</td>
</tr>
<tr>
<td>CRP</td>
<td>0.9b</td>
<td>2.3c</td>
</tr>
<tr>
<td>NT28</td>
<td>5.9a</td>
<td>7.1ab</td>
</tr>
<tr>
<td>NT4</td>
<td>2.3b</td>
<td>8.6a</td>
</tr>
<tr>
<td>CT</td>
<td>6.6a</td>
<td>5.1b</td>
</tr>
</tbody>
</table>

* a mg N mineralized 1000 kg⁻¹ soil/mg CO2-C or MBC kg⁻¹ soil.

b Significant management differences for each parameter in a particular soil depth are indicated by different letters (P = 0.05) using Duncan’s multiple range test.
with the ratios of Nmin/MBC and Nmin/CO₂ biological N cycling and N retention. However, MBC and POM-N, along
for increasing TSN of depleted soil, our hypothesis was that practices
soil quality due to over 100 years of cultivation. Considering strategies
and the lowest amount in CT, clearly indicated a rapid deterioration of
4. Conclusions

There was an overall increase in MBC, TSN, and POM-N in NT and
CRP soil compared to CT soil. The highest microbial biomass was in NP
and the lowest amount in CT, clearly indicated a rapid deterioration of
soil quality due to over 100 years of cultivation. Considering strategies
for increasing TSN of depleted soil, our hypothesis was that practices
that included NT and CRP would result in an increased soil N pool as
compared to CT in the following order: CT < NT4 < CRP < NT28 < NP.
Our data, however, deviated significantly from this sequence.
Unexpectedly CRP failed to increase TSN contents as compared to
CT. In addition, the adoption of NT seemed to improve the soil
biological N cycling and N retention. However, MBC and POM-N, along
with the ratios of Nmin/MBC and Nmin/CO₂ may be sensitive indicators of management-induced changes in TSC and TSN. The
potential for better utilization of MBC and TSN reserves in NT and CRP
soils depends on our understanding of their distribution in soil and
associated factors of management and time which influence their
depletion and accretion. Understanding the microbial response
of tillage related changes and N cycling under different NT and CRP
management systems is important to the development of precise nutrient manage-
ment systems to maintain soil quality.

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