Cropping system influences on several soil quality attributes in the northern Great Plains

Brian J. Wienhold and Ardell D. Halvorson

Interpretive summary

Soil quality is becoming as large a public concern as air and water quality. Traditional farming practices in semi-arid regions, such as crop-fallow systems, are leading to a deterioration in soil quality. New farming practices being developed produce a crop every year, utilize conservation tillage, and apply fertilizer in amounts that will meet the needs of the crop and minimize the potential for environmental contamination. This study compared soil quality in a traditional crop-fallow system to that in an annual cropping system. Results suggest that soil quality is improved with an annual cropping system and that soil quality improves with use of conservation tillage in either system. Farmers can reverse the deterioration in soil quality by adopting more intensive cropping practices using minimum and no-till systems.

Key words: conservation tillage, crop rotation, organic carbon, organic nitrogen, microbe numbers, summer fallow.

ABSTRACT: Crop-fallow using conventional mechanical tillage has been the traditional management practice for farmers in the semi-arid northern Great Plains. This practice reduces soil quality and is not sustainable. More intensive management systems utilizing reduced- or no-tillage, fertilization to meet a yield goal, and systems producing a crop annually are being developed. In 1984, a study was initiated to compare crop yield, water-use efficiency, and nutrient-use efficiency under a spring wheat-fallow system to that under a spring wheat-winter wheat-sunflower annual cropping system. In 1995, soil samples were collected and laboratory analyses performed to quantify a number of soil quality attributes and determine the effect these management practices have had on soil quality after 11 years. Soil quality attributes were greater under annual cropping than under crop-fallow and improved as tillage intensity decreased. These results suggest that the more intensive management strategies are more sustainable.

Crop-fallow using conventional mechanical tillage has been the common management practice for farmers in the semiarid northern Great Plains. In this region, water is the factor that most often limits crop production. Following allows soil water to accumulate for use by a subsequent crop thereby reducing the incidence of crop failure. Research has demonstrated that water storage efficiency during fallow is lower than that of annual cropping systems (Peterson et al. 1996). In addition, following results in a deterioration in soil quality and is not a sustainable practice (Campbell and Souster 1982). During the fallow period the soil is vulnerable to wind and water erosion, is in a more oxidative state due to increased cultivation, and receives lower crop residue inputs (Rasmussen and Collins 1991). These processes result in a loss of organic matter from soil in a crop-fallow system (Haas et al. 1957; Unget 1982). Several studies have reported that as incidence of fallow decreases, loss of soil organic C decreases (Dormaar and Pittman 1980; Biederbeck et al. 1984).

In recent years, a number of more intensive management strategies have been demonstrated as being economically vi-

J. Soil and Water Cons. 53(3) 254-258

Mention of trade names or proprietary products does not indicate endorsement by USDA and does not imply its approval to the exclusion of other products that may be suitable.
rows. All phases of each rotation were presented each year resulting in five fields per replication. The cropping systems were replicated three times. Within each cropping system there were three tillage treatments (conventional tillage, minimum tillage, and no-tillage), and N was applied during the crop year at rates of 0, 22, and 45 kg ha⁻¹ (0, 20, and 40 lbs ac⁻¹) in the crop-fallow system and each year at rates of 34, 67, and 101 kg ha⁻¹ (30, 60, and 90 lbs ac⁻¹) in the annual cropping system. The reduced N-rates in the crop-fallow system are necessary to compensate for the inorganic N that accumulates during the fallow period in this system. Treatment plots were 46 m x 24 m (150 x 80 ft) and were of sufficient size to allow use of field scale equipment for all operations. Conventional tillage utilized an undercutter (sweep plow), a chisel plow, and a double disc in the fall and spring to control weeds, incorporate crop residue, and prepare the seedbed. Minimum tillage utilized one or two tillages with an undercutter in the spring and herbicides to control weeds. No-tillage relied solely on herbicides for weed control. Surface residue covered <30% of the soil under conventional tillage, between 30% and 60% under minimum tillage, and >60% under no-tillage.

In the spring of 1995, prior to field operations, soil samples were collected from the 0 to 5 cm (0 to 2 in) and 5 to 15 cm (2 to 6 in) depths of all treatment plots. The 270 samples were stored at -5°C (23°F) until the laboratory analyses were conducted.

**Laboratory methods.** A number of soil properties were measured to evaluate the effect of the various management practices on soil quality. Bulk density was measured as a soil physical property and was determined gravimetrically from duplicate cores collected from each treatment (Blake and Hartge 1986).

Total organic C, total N, and inorganic N were chosen as chemical attributes of soil quality. Total N and organic C were determined by dry combustion using a Carlo-Erba Na 1500 NCS analyzer (Carlo Erba Instruments, Milan, Italy). Inorganic N was measured in 0.01 M CaSO₄ extracts colorimetrically using a Lachat flow injection ion analyzer (Zellweger Analytics, Lachat Instruments Div., Milwaukee, WI).

Fungi, bacteria, and actinomycete numbers were chosen as biological attributes of soil quality. Microbe numbers were determined by plating a serial dilution of a soil-water suspension on selective media. Bacteria were grown on trypsin soy agar, actinomycetes were grown on starch-casein agar, and fungi were grown on Martin’s rose bengal agar (Wollum 1982).

**Data analysis.** The field study has a strip-strip randomized block design with N-rates as strips going one direction, tillage treatments as perpendicular strips, and the cropping systems being the whole plot treatments. There were three valid models for testing the effect of N-rate and tillage on the soil quality attributes. The first model compared the effect of N-rate and tillage on soil quality attributes within the crop-fallow system. Soil quality attributes where a crop was grown the previous year were compared to those where soils were fallowed the previous year. The second model compared the effect of N-rate and tillage on soil quality attributes between the crop-fallow system and the annual cropping system. Soil quality attributes where spring wheat was grown the previous year in the crop-fallow system were compared to those of soils where spring wheat was grown the previous year in the annual cropping system. This model compared soil quality attributes of soil cropped every other year to those of soil cropped annually. The third model compared the effect of N-rate and tillage on soil quality attributes within the annual cropping system. Soil quality attributes of soils where either spring wheat, winter wheat, or sunflowers were grown the previous year in the annual cropping system were compared. The three models were analyzed using ANOVA with differences declared significant at P < 0.05. Results are reported as means ± SEM.
Table 3. Bulk density (g cm\(^{-3}\)) and fungi numbers (10\(^7\) m\(^{-2}\)) as a function of previous years crop and tillage* in the 0 to 5 cm layer of the annual cropping system

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Spring wheat</th>
<th>Winter wheat</th>
<th>Sunflower</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CT</td>
<td>MT</td>
<td>NT</td>
</tr>
<tr>
<td>Bulk density</td>
<td>1.28 ± 0.06</td>
<td>1.34 ± 0.03</td>
<td>1.37 ± 0.03</td>
</tr>
<tr>
<td>Fungi numbers</td>
<td>90.8 ± 6.2</td>
<td>78.9 ± 6.5</td>
<td>61.2 ± 6.5</td>
</tr>
</tbody>
</table>

* CT = Conventional tillage, MT = Minimum tillage, and NT = No-tillage

Results and discussion

Soil quality within the crop-fallow system. Bulk density, the physical soil quality attribute, was higher in surface soil that had been fallowed the previous year than in surface soil that supported spring wheat the previous year (Table 1). Bulk density increased as tillage intensity decreased in surface soils from both stages (Table 1). Bulk density averaged 1.31 ± 0.02 g cm\(^{-3}\) and was similar among treatments for soil from the 5 to 15 cm (2 to 6 in) layer.

Chemical attributes of soil quality were similar for the two stages of the crop-fallow system. Surface soil total N content averaged 1.22 ± 0.06 Mg ha\(^{-1}\) (0.54 ± 0.03 tons a\(^{-1}\)), total organic C content averaged 17.41 ± 0.83 Mg ha\(^{-1}\) (7.76 ± 0.37 tons a\(^{-1}\)), and inorganic N content averaged 6.97 ± 0.54 kg ha\(^{-1}\) (2.62 ± 0.48 lbs a\(^{-1}\)). In the 5 to 15 cm (2 to 6 in) soil layer, total N content averaged 1.50 ± 0.07 Mg ha\(^{-1}\) (0.67 ± 0.03 tons a\(^{-1}\)), total organic C content averaged 21.06 ± 0.92 Mg ha\(^{-1}\) (9.39 ± 0.41 tons a\(^{-1}\)), and inorganic N content averaged 9.98 ± 0.48 kg ha\(^{-1}\) (3.91 ± 0.43 lbs a\(^{-1}\)). Chemical attributes were not affected by tillage treatment or N-rate in either soil layer of this system. (Campbell et al. 1995) also reported no response in soil organic matter to tillage or N-rate in a crop-fallow system in southern Canada.

Biological attributes of soil quality varied with tillage treatment and cropping phase. Fungi numbers were higher in surface soil fallowed the previous year than in surface soil where spring wheat was grown the previous year (Table 1). Fungi numbers were higher in minimum tilled surface soils from both cropping phases in this system (Table 1). Fungi numbers in soil from the 5 to 15 cm (2 to 6 in) depth were similar for the two stages but differed among tillage treatments. Fungi numbers averaged 62.3 ± 5.2 x 10\(^9\) m\(^{-2}\) (5.6 ± 0.5 x 10\(^9\) ft\(^{-2}\)) under conventional tillage, 63.1 ± 5.1 x 10\(^9\) m\(^{-2}\) (5.9 ± 0.5 x 10\(^9\) ft\(^{-2}\)) under minimum tillage and 53.9 ± 4.2 x 10\(^9\) m\(^{-2}\) (5.0 ± 0.4 x 10\(^9\) ft\(^{-2}\)) under no-tillage. Under more intensive tillage, crop residue is incorporated into the soil and is more readily available to fungi. Under no-tillage the crop residue remains on the soil surface where it is less available and conditions are harsher for microbial activity. Bacteria numbers were similar among treatments and averaged 16.7 ± 1.6 x 10\(^6\) m\(^{-2}\) (1.6 ± 0.1 x 10\(^6\) ft\(^{-2}\)) in soil from the 0 to 5 cm (0 to 2 in) depth and 21.4 ± 1.4 x 10\(^6\) m\(^{-2}\) (2.0 ± 0.1 x 10\(^6\) ft\(^{-2}\)) in soil from the 5 to 15 cm (2 to 6 in) depth. Actinomycete numbers were similar to the two cropping phases averaging 13.3 ± 1.2 x 10\(^6\) m\(^{-2}\) (1.2 ± 0.1 x 10\(^6\) ft\(^{-2}\)) in soil supporting spring wheat the previous year and 14.0 ± 1.1 x 10\(^6\) m\(^{-2}\) (1.3 ± 0.1 x 10\(^6\) ft\(^{-2}\)) in the surface of soil fallowed the previous year. Actinomycete numbers were higher in soil from the 5 to 15 cm (2 to 6 in) layer that had been fallowed the previous year. At that depth actinomycete numbers averaged 17.2 ± 1.6 x 10\(^6\) m\(^{-2}\) (1.6 ± 0.1 x 10\(^6\) ft\(^{-2}\)) where spring wheat was grown the previous year and 26.7 ± 2.5 x 10\(^6\) m\(^{-2}\) (2.5 ± 0.2 x 10\(^6\) ft\(^{-2}\)) in soil fallowed the previous year. 

Crop-fallow versus annual cropping. Bulk density was greater in soil of the annual cropping system than in soil of the crop-fallow system and increased as tillage intensity decreased in both systems (Table 2). Treatment effects on bulk density were apparent in both soil layers (Table 2).

The chemical attributes of soil quality varied between the two systems and among the tillage treatments. In the annual cropping system total N content and total organic C content (Table 2) were greater under no-tillage in surface soil and under all tillage practices in soil from the 5 to 15 cm (2 to 6 in) depth than in soil from the crop-fallow system. Tillage intensity did not affect total N or organic C content in either soil layer of the crop-fallow system. For the annual cropping system total N and total organic C content increased in the surface layer as tillage intensity decreased. Tillage did not affect total N or total organic C content at the 5 to 15 cm (2 to 6 in) soil depth for the annual cropping system. Inorganic N content was similar for both systems and averaged 8.29 ± 0.47 kg ha\(^{-1}\) (7.40 ± 0.42 lb a\(^{-1}\)) at the 0 to 5 cm (0 to 2 in) depth and 7.94 ± 0.44 kg ha\(^{-1}\) (7.09 ± 0.39 lb a\(^{-1}\)) at the 5 to 15 cm (2 to 6 in) depth.

The number of fungi was the only biological soil quality attribute that varied between the two cropping systems and among the tillage treatments (Table 2). Fungi numbers were greater in soil from the 0 to 5 cm (0 to 2 in) depth of the annual cropping system than from the crop-fallow system. In the crop-fallow system fungi numbers were greater in soil with the minimum tillage treatment than soil in the conventional tillage or no-tillage system. With annual cropping fungi numbers decreased as tillage intensity decreased, likely a response to the amount of crop residue incorporated and available as a substrate for fungal growth. Bacteria and actinomycete numbers were similar for the two systems and among the tillage practices. Bacteria averaged 13.6 ± 1.1 x 10\(^6\) m\(^{-2}\) (1.3 ± 0.1 x 10\(^6\) ft\(^{-2}\)) at the 0 to 5 cm (0 to 2 in) depth and 18.8 ± 1.1 x 10\(^6\) m\(^{-2}\) (1.7 ± 0.1 x 10\(^6\) ft\(^{-2}\)) at the 5 to 15 cm (2 to 6 in) depth. Actinomycetes averaged 12.6 ± 0.9 x 10\(^6\) m\(^{-2}\) (1.2 ± 0.1 x 10\(^6\) ft\(^{-2}\)) at the 0 to 5 cm (0 to 2 in) depth and 18.5 ± 1.3 x 10\(^6\) m\(^{-2}\) (1.7 ± 0.1 x 10\(^6\) ft\(^{-2}\)) at the 5 to 15 cm (2 to 6 in) depth.

As the incidence of fallow is reduced, fertilizer and crop residue inputs increase. Crop residue serves as a substrate for soil microbes and as this substrate increases in amount microbial numbers, biomass N and C, and microbial activity increase (Biederbeck et al. 1984; Janzen 1987; Campbell et al. 1989). Over time the increased crop residue inputs and subsequent microbial activity results in an increase in soil organic C and N content (Biederbeck et al. 1984; Janzen 1987).
Table 4. Chemical soil attributes as a function of tillage in the annual cropping system

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Conventional tillage</th>
<th>Minimum tillage (0 to 5 cm)</th>
<th>No-tillage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total N (Mg ha⁻¹)</td>
<td>1.27 ± 0.07*</td>
<td>1.47 ± 0.06</td>
<td>1.46 ± 0.07</td>
</tr>
<tr>
<td>Organic C (Mg ha⁻¹)</td>
<td>18.05 ± 1.06</td>
<td>21.08 ± 0.95</td>
<td>20.45 ± 1.05</td>
</tr>
<tr>
<td>Inorganic N (kg ha⁻¹)</td>
<td>8.30 ± 0.57</td>
<td>9.75 ± 0.59</td>
<td>11.44 ± 0.74</td>
</tr>
</tbody>
</table>

| Total N (Mg ha⁻¹) | 1.54 ± 0.10 | 1.59 ± 0.11 | 1.62 ± 0.08 |
| Organic C (Mg ha⁻¹) | 21.94 ± 1.45 | 22.45 ± 1.56 | 25.78 ± 1.18 |
| Inorganic N (kg ha⁻¹) | 8.41 ± 0.72 | 8.32 ± 0.79 | 10.37 ± 0.66 |

* Mean ± SEM

Campbell et al. (1995). Increases in microbial numbers, organic C content, and total N content are greater under conservation tillage than under conventional tillage (Linn and Doran 1984; Havlin et al. 1990; Grant and Ladıp 1994). Increases in chemical and biological properties usually occur in the surface 10 to 15 cm (4 to 6 in) under conservation tillage and are similar or lower under conventional tillage at lower depths than under conventional tillage (Doran 1980; Linn and Doran 1984).

The soil quality parameters measured in this study did not respond to the N-rate treatments. Campbell et al. (1991b) reported that soil organic matter did not respond to N-rate in a soil initially having a relatively high clay and organic matter content but did increase in a coarser textured soil initially having a relatively low organic matter content (Campbell et al. 1991a).

Soil quality within the annual cropping system. Bulk density varied with crop and tillage practice (Table 3). Bulk density was lowest in soil supporting winter wheat the previous year and highest in soil supporting sunflower the previous year. In soil supporting spring wheat the previous year bulk density increased as tillage intensity decreased while in soil supporting winter wheat and sunflower the previous year bulk density was greatest in minimum tilled soil and lower in conventionally tilled and no-tilled soil.

Chemical soil quality attributes were similar for soils supporting the three crops but varied among the tillage practices (Table 4). Total N content, organic C content, and inorganic N content were greater under minimum and no-tillage than under conventional tillage in the 0 to 5 cm (0 to 2 in) layer. In the 5 to 15 cm (2 to 6 in) layer, total N content, organic C content, and inorganic N content were greater under no-tillage than under conventional or minimum tillage (Table 4). Campbell et al. (1995) reported higher organic matter with no-tillage than with conventional tillage in the surface soil layer for a continuous wheat system in southern Canada.

Fungi numbers increased as tillage intensity decreased in soil from the 0 to 5 cm (0 to 2 in) layer supporting spring wheat the previous year and decreased as tillage intensity decreased in soil from the 0 to 5 cm (0 to 2 in) layer supporting winter wheat and sunflower the previous year (Table 3). Fungi numbers in soil from the 5 to 15 cm (2 to 6 in) layer were similar among the treatments and averaged 85.7 ± 3.8 × 10⁶ m⁻² (8.0 ± 0.4 × 10⁸ fr⁻¹). Bacteria averaged 14.9 ± 1.4 × 10⁶ m⁻² (1.4 ± 0.1 × 10⁸ fr⁻¹) in soil from the 0 to 5 cm (0 to 2 in) layer, 20.2 ± 1.1 × 10⁶ m⁻² (1.9 ± 0.1 × 10⁸ fr⁻¹) in soil from the 5 to 15 cm (2 to 6 in) layer, and were similar for treatments. Likewise, actinomycete numbers were similar for the treatments and averaged 13.2 ± 0.9 × 10⁸ m⁻² (1.2 ± 0.1 × 10¹⁰ fr⁻¹) in the 0 to 5 cm (0 to 2 in) layer and 21.0 ± 1.2 × 10⁸ m⁻² (2.0 ± 0.1 × 10¹⁰ fr⁻¹) in the 5 to 15 cm (2 to 6 in) layer.

Differences in physical and biological soil quality attributes among soil supporting the various crops in the annual cropping system (Table 3) are likely due to the length of time between crop harvest and post-harvest tillage (residue input) in late summer or fall and sampling the following spring. Fall tillage would have been performed in the appropriate fields of both spring wheat and winter wheat, which explains the lower bulk density values with the conventional and minimum tillage treatments of those two crops (Table 3). Sunflowers are harvested late in the fall and no tillage was performed on any of the sunflower fields prior to sampling. The lack of tillage in no-tillage fields explains the higher bulk density values.

Crop residues are colonized by soil microbes and during decomposition microbial populations will increase to utilize the available substrate. Residues with the conventional tillage treatment and to a lesser extent with the minimum tillage treatment are incorporated and are readily available to soil microbes. For these tillage systems microbial populations will increase initially and then decline as the substrate is utilized. For the no-tillage system and to a lesser extent the minimum tillage system residue is less available to soil microbes and decomposition proceeds more slowly. For conservation tillage systems substrate will be available to soil microbes for a longer period of time and larger populations may be supported. Larger fungi numbers in conventionally tilled and minimum tilled soil supporting spring wheat (Table 3) may represent a flush of microbial activity that occurred due to the incorporation of the spring wheat residue the previous fall. Little microbial activity would be expected on residue incorporated in the fall as the soils will freeze shortly after tillage, but these residues would be readily available for microbial decomposition the following spring.

Responses of chemical soil quality attributes to tillage in this study are similar to those reported by others (Doran 1980; Linn and Doran 1984; Havlin et al. 1990; Grant and Ladıp 1994). Increases in organic C and N associated with a decline in tillage intensity have usually been limited to the 0 to 7.5 cm (0 to 3 in) layer. In the present study we measured an increase in total N content, organic C content, and inorganic N content in the 5 to 15 cm (2 to 6 in) layer as well, with values being greatest in no-tillage soils. The increase detected in the present study may in part be due to sampling the 5 to 15 cm (2 to 6 in) depth while the other cited studies sampled the 7.5 to 15 (3 to 6 in) depth. Another explanation may be that most of the other cited studies were conducted in soil supporting row crops while the present study utilized soil supporting cereal crops two out of three years.

Conclusions

More intensive cropping increased a number of the soil quality attributes assessed in this study. These increases are likely due to the annual addition of fertilizer and crop residue to the soil in the annual cropping system. This increase was detected in both soil layers sampled with larger differences between the two cropping systems in the 5 to 15 cm (2 to 6 in) than in the surface layer. This suggests that abandoning crop-fallow in favor of a more intensive cropping system may be the most important decision a producer can make to impact soil quality. In both cropping systems, conservation tillage in-
creased the value of a number of soil quality attributes. While others have shown that annual cropping combined with conservation tillage is economical, our results suggest that these more intensive cropping systems are also more sustainable than the traditional conventional tillage, crop-follow system.

REFERENCES CITED


