Components of surface soil structure under conventional and no-tillage in northwestern Canada

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Abstract

Improvement in soil quality to maintain high production and reduce negative environmental impacts is necessary for alternative crop production strategies to become socially acceptable and viable in the long-term. No-tillage (NT) management of the predominantly small grain region of western Canada has the potential to curb soil erosion and increase profitability. An understanding of the direct effects of NT on soil properties is necessary to evaluate its potential for sustained long-term productivity. We have compiled data collected from two sites in northern British Columbia to ascertain the long-term effects of conventional tillage (CT) and NT on soil components thought to be important in surface soil structural improvement. Soil water retention was greater under NT compared with CT without dramatically altering bulk density due to redistribution of pore size classes into more small pores and less large pores. Soil organic C was greater under NT than under CT nearest the soil surface. Water-stable aggregation improved under NT compared with CT, perhaps because more soil organic C was sequestered within macroaggregates under NT compared with CT that helped to stabilize these aggregates. Steady-state water infiltration was greater under NT than under CT as a result of soil structural improvements associated with surface residue accumulation and lack of soil disturbance. Barley (*Hordeum vulgave* L.) yield tended to be greater under NT than under CT in years of low rainfall as a result of improvements in soil water retention and transmission that may have provided a better environment for root development. Our data indicate that NT is a viable management strategy to improve soil quality in the cold, semiarid region of western Canada. This strategy could lead to high production, minimal negative environmental impacts, and a socially-acceptable farming system. © 1999 Elsevier Science B.V. All rights reserved.

1. Introduction

Public awareness about the state of our environment is growing worldwide. Recently, several reports have been published to highlight the importance of soil quality in achieving sustainble farming systems, which attempt to balance productivity, profitability, and environmental protection (Brundtland, 1987; Rodale Institute, 1991; Acton and Gregorich, 1995). Soil quality can be linked to sustainable farming systems with the goal of improving the functioning of soil.

Two important functions of soil are retention and transmission of water, which directly impact plant

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productivity and the environment. Water stored in the soil profile is essential for plants and other organisms to survive periods without rainfall. Movement of water through the soil profile, rather than as runoff, provides important environmental benefits to increased groundwater recharge, reduced erosion, and reduced off-site sediment deposition. Storage and movement of water are largely controlled by structural aspects of soil, especially near the soil surface where crust formation and compaction can seal the surface (Duley, 1939; Morin et al., 1989). Biological, physical, and chemical processes continually interact with time resulting in a diversely arranged mixture of soil minerals, organic matter, and pore spaces, which together define soil structure (Juma, 1993).

Mechanical tillage, besides preparing a seedbed and controlling weeds, can alter the balance of air and water in soil necessary for optimum plant growth. Despite the many benefits of tillage to crop establishment and production in the past, new herbicide and minimum-tillage management systems have drastically changed today's methods of crop production. Surface residue accumulation with NT now mimics natural ecosystems, although the extent of biological intervention in improving soil structural features in these managed systems needs to be characterized. Soil structural changes with NT crop production systems in the cold, semiarid climate of northwestern Canada have not received much attention.

The effects of NT compared with CT on some soil chemical (Arshad et al., 1990; Franzluebbers and Arshad, 1996c), physical (Azooz and Arshad, 1995; Arshad and Azooz, 1996; Azooz et al., 1996), and biological properties (Franzluebbers and Arshad, 1996a,b, 1997) have been recently reported for soils in the Peace River region of northern Alberta and British Columbia. Our objectives were to summarize these findings and present additional information with particular emphasis on changes in surface soil structural characteristics due to adoption of NT.

2. Methods

2.1. Field experiments

Field experiments were initiated in 1979 on a Donnelly silt loam near Dawson Creek, British Columbia ($55°46'$N, $120°21'$W) and in 1988 on a Donnelly sandy loam near Rolla, British Columbia ($55°42'$N, $120°10'$W). Both soils have been classified as Gray Luvisols (USDA: Typic Cryoboralfs: FAO: Podzoluvisol). The silt loam contained an average of 260 g clay per kg soil and 25 g organic C per kg soil in the 0–225 mm depth, and 560 g clay per kg soil and 10 g organic C per kg soil in the 225–300 mm depth. The sandy loam contained an average of 180 g clay per kg soil and 20 g organic C per kg soil in the 0–225 mm depth and 305 g clay per kg soil and 10 g organic C per kg soil in the 225–300 mm depth (Azooz and Arshad, 1995). Annual temperature averages $0.9°C$ and precipitation averages 504 mm, with 289 mm occurring during the crop growing period from May through September (Fig. 1). Rainfall distribution is erratic and unpredictable, and crops can suffer from moisture deficits even during years receiving the mean precipitation.

Barley (*Hordeum vulgare* L.) was grown continuously on the silt loam and barley and canola (*Brassica campestris* L.) were rotated on the sandy loam. Both soils were managed with CT and NT. Conventional tillage consisted of chiselling to a depth of 120–150 mm after harvest and disking twice to a depth of 80–100 mm in the spring. No soil disturbance occurred with NT except for planting. Both crops were seeded with a double-disk press drill in 170 mm-wide rows. Tillage treatments at both locations were arranged as side-by-side, unreplicated blocks (>5 ha) across a gently rolling topography.

2.2. Soil sampling and analysis

Soil samples were collected from three to four paired locations. Sampling for soil structural properties was from 1980 to 1995 in the silt loam and from 1992 to 1995 in the sandy loam. Readers are referred elsewhere for detailed description of methods for bulk density (Azooz et al., 1996; Franzluebbers and Arshad, 1996b), saturated hydraulic conductivity, pore size distribution, and water retention (Azooz et al., 1996), water-stable aggregation and soil organic C (Franzluebbers and Arshad, 1996c), carbohydrates (Arshad et al., 1990), and microbial biomass and mineralizable C and N (Franzluebbers and Arshad, 1996b, 1997).
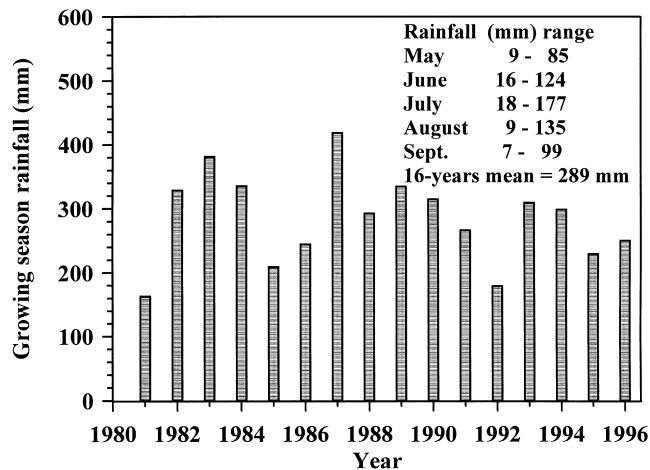
Fig. 1. Mean precipitation during the growing season (May through September) from 1988 to 1996.

Infiltration was determined on the silt loam using a double ring infiltrometer during 1991. Inner (105 mm dia.) and outer (305 mm dia.) rings (300 mm depth) were inserted 100 mm into the soil. Cheesecloth was placed on the soil surface to minimize soil disturbance. A constant head of 100 mm water was maintained in both rings.

3. Results and discussion

3.1. Soil bulk density

Soil bulk density was not different between tillage systems in either soil during summer 1992 (Azooz et al., 1996) or during spring 1995 (Franzluebbers and Arshad, 1996b). Bulk density did differ with unmanaged variables, such as soil type and soil depth. Results from several studies have shown an increase in soil bulk density with the conversion of CT to NT (Hill, 1990; Wu et al., 1992; Gregorich et al., 1993). However, a study conducted in Minnesota indicated that soil bulk density increased with NT relative to CT during the first two years, but then became similar at four years, and even lower with increasing time under NT (Voorhees and Lindstrom, 1984), which was likely due to improved soil structural stability. Soil bulk density should be considered a first approximation of potential changes in soil structure with improved management.

3.2. Soil pore size distribution and water retention

Although total porosity was not affected by NT compared with CT to a depth of 0.3 m at the end of 13 years in the silt loam and four years in the sandy loam, distribution of pore sizes was affected (Azooz et al., 1996). Both soils contained more micropores (<0.75 μm) under NT than under CT, but less macropores (>15 μm) under NT than under CT. Small pores between 0.1 and 15 μm are assumed to retain more plant-available water than larger pores that tend to drain quickly after rainfall (Hill et al., 1985).

Water retention along a soil matric pressure gradient indicated that soil under NT retained more water than under CT during unsaturated conditions in both soils (Fig. 2). This could be attributed to the greater volume fraction of micropores under NT than under CT.

3.3. Soil aggregation

Mean weight diameter of water-stable aggregates at a depth of 0–75 mm was greater under NT than under CT throughout the growing season in the silt loam during 1989 through 1991 (Fig. 3). Seasonal differences in mean-weight diameter appeared to have been a result of crop rooting or soil drying that decreased the difference between NT and CT later in the year. Water-stable macroaggregation (>0.25 mm) of both soils was 50–60% greater under NT than under CT at a
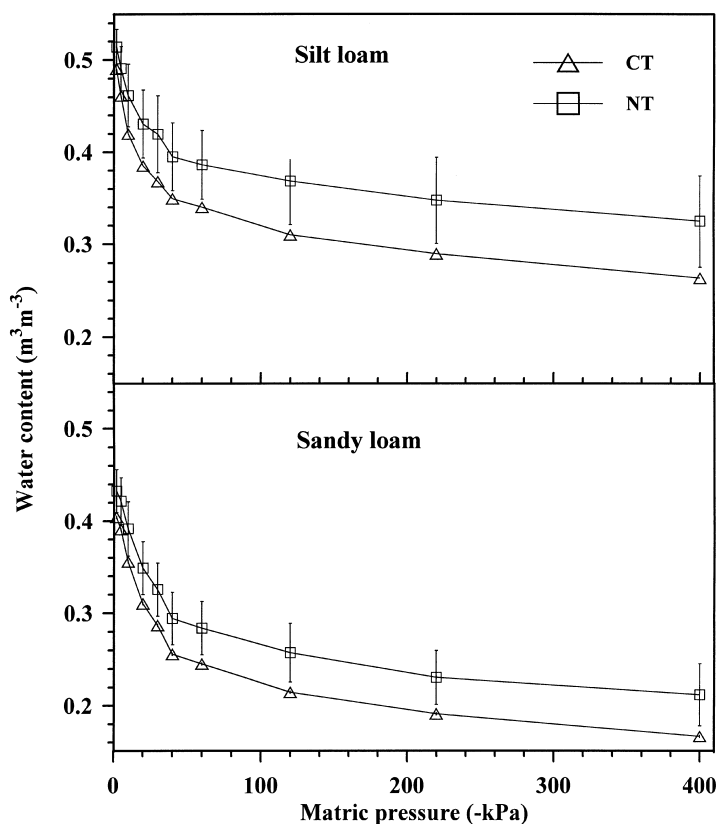
Fig. 2. Water retention of the silt loam and sandy loam soils as affected by tillage system (CT, conventional tillage and NT, no-tillage) during 1992. Vertical bars represent LSD$_{0.05}$.

depth of 0–50 mm, but not different at a depth of 125–200 mm (Franzluebbers and Arshad, 1996c).

3.4. Soil carbon pools

Soil organic C concentration in 1994 was greater under NT than under CT at a depth of 0–50 mm in the silt loam, only at a depth of 0–25 mm in the sandy loam, and not different between tillage systems below this depth (Table 1). Arshad et al. (1990) reported a significant increase in soil organic C concentration under NT compared with CT at a depth of 0–75 mm in the silt loam in 1988. Adjusting soil organic C to an areal estimate to include bulk density resulted in no change due to tillage at any depth for either soil in 1995 (Franzluebbers and Arshad, 1996c). Many studies in more temperate regions have reported substantial increases in soil organic C with NT compared

with CT, especially near the soil surface (Dick, 1983; Blevins et al., 1983; Franzluebbers et al., 1995). However, small or no changes in soil organic C with adoption of NT have been reported in other cold regions of North America (Carter and Rennie, 1982; Angers et al., 1997).

Measurement of the more active fractions of soil organic C has been suggested as an early way to elucidate the potential changes in soil organic matter that will occur with time under different management systems (Powlson et al., 1987). Soil microbial biomass C at a depth of 0–200 mm in 1995 was not different between tillage systems in either soil (Franzluebbers and Arshad, 1996b). However, basal soil respiration was lower under NT compared with CT, especially immediately below the soil surface (Franzluebbers and Arshad, 1996b). Lower respiration in the NT may be due to less exposure of soil to oxygen, thus
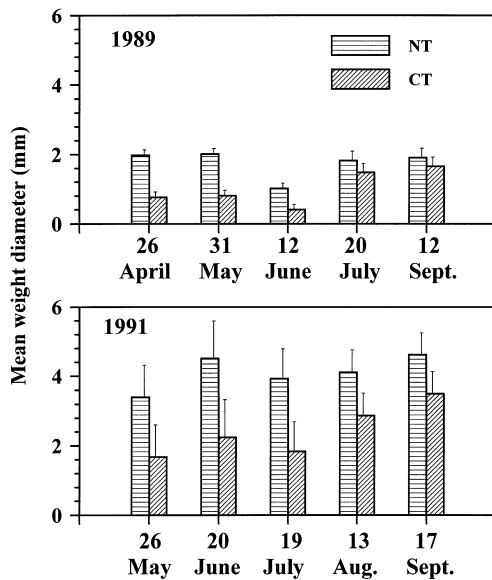
Fig. 3. Mean weight diameter of water-stable aggregates in the silt loam during 1989–1991 as affected by season and tillage system (CT, conventional tillage and NT, no-tillage). Paired bars with different letters are different at $P < 0.05$.

does the soil under NT, thereby limiting decomposition.

Soil carbohydrate concentration under NT in the sandy loam during 1992 averaged 21% greater than under CT at a depth of 0–25 mm, 13% greater at a depth of 25–50 mm, and 5% greater at a depth of 50–100 mm (Table 2). Soil carbohydrate concentration at a depth of 0–75 mm was 10% greater under NT than under CT in the silt loam during 1988 (Arshad et al., 1990). Soil carbohydrates are considered important plant and microbial components in stabilizing soil macroaggregates (Oades, 1993).

Soil organic C content isolated within macroaggregates was greater under NT than under CT in both soils at a depth of 0–125 mm in 1995 (Franzluebbers and Arshad, 1996c). Soil organic C was also more protected from decomposition within macroaggregates in both soils under NT compared with CT (Franzluebbers and Arshad, 1997), which probably led to greater stability of aggregates under NT.

3.5. Infiltration

Steady-state infiltration in the silt loam during 1991 was 60% greater under NT than under CT (Fig. 4). Saturated hydraulic conductivity in both soils during 1992 was also greater under NT than under CT (Azooz et al., 1996). From the investigations of various other soil properties presented above, it appears that improvement in soil organic C and its allocation and protection within macroaggregates that lead to improved aggregate size distribution and stability

resulting in more storage and increase of organic matter under the no-tillage system. It is also probable that in this cold, semiarid climate, a wetter soil under NT may lead to increased in situ decomposition of crop residues and native soil organic C. The shallow tillage employed with CT may be placing much of the crop residues near the soil surface, where this tilled soil tends to dry more frequently and completely than

Table 1
Soil organic C concentration (g kg^{-1} soil) during 1994 as affected by tillage system and soil depth

Tillage system	0–25 mm	25–50 mm	50–75 mm	75–100 mm
Silt loam				
Conventional tillage	33.3	31.5	30.2	25.0
No-tillage	44.5	36.4	27.3	24.0
t-test significance	[a]	[a]	NS[c]	NS[c]
Sandy loam				
Conventional tillage	22.0	22.2	20.0	20.0
No-tillage	24.3	22.5	19.0	19.0
t-test significance	[b]	NS[c]	NS[c]	NS[c]

[a] Significant at $P \leq 0.05$.
[b] Significant at $P \leq 0.1$.
[c] Not significant.

Table 2
Soil carbohydrate concentration (g kg^{-1} soil) in the sandy loam soil during 1992 as affected by tillage system and soil depth

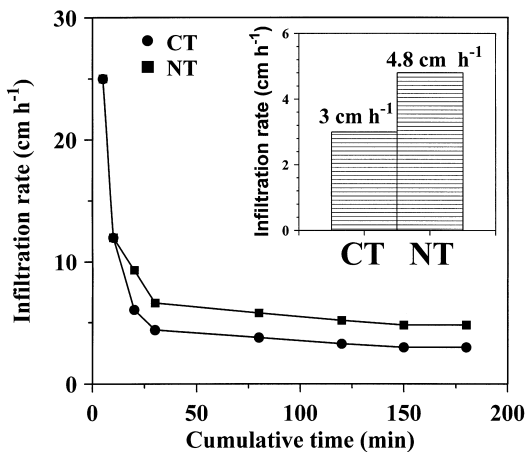| Tillage system	0–25 mm	25–50 mm	50–100 mm	0–100 mm
Conventional tillage	5.0	4.8	4.5	4.8
No-tillage	6.1	5.5	4.7	5.4
t-test significance	NS[b]	NS[b]	NS[b]	[a]

[a] Significant at $P \leq 0.1$.
[b] Not significant.

Fig. 4. Infiltration in the silt loam during 1992 as affected by tillage system (CT, conventional tillage and NT, no-tillage).

when soil is undisturbed have together contributed to improved water infiltration under NT.

Despite a greater portion of the total pores were smaller under NT compared with CT, greater water infiltration may have occurred under NT due to a more continuous network of pores compared with a discontinuous network of pores caused by tillage events under CT (Kay, 1990).

3.6. Crop yield

Crop yield averaged from 1981 to 1992 in the silt loam was not affected by tillage system (Fig. 5). During the wetter years of 1986–1990, yield was reduced with NT compared with CT. However during many of the drier years, yield was improved with NT compared with CT. Lafond and Derksen (1996) reported similar improvement in yield under NT compared with CT, especially during hot or dry years in Saskatchewan. Reduction in yield during wetter years and improvement in yield during drier years was likely a reflection of maintaining higher plant-available water throughout the growing season under NT compared with CT (Arshad and Dobb, 1991). More water retained in the crop rooting zone under NT compared with CT was thought to be the primary cause for increased grain yield in Saskatchewan (Brandt, 1992).
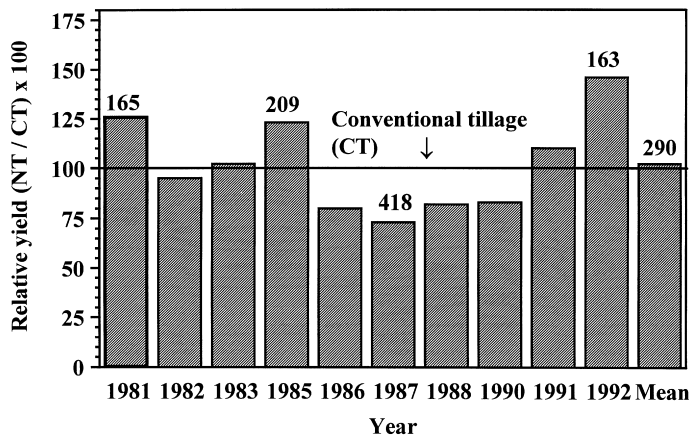

Fig. 5. Barley grain yield on the silt loam as affected by tillage system during 1981–1992. Value above bars within a year indicates growing-season precipitation.

4. Conclusions

Continuous long-term NT management on a silt loam and a sandy loam in northern British Columbia improved total and structurally important components of soil organic matter near the soil surface, aggregate size distribution and stability, and water transmission and storage. Our data demonstrate that crop production with NT can be successfully used to control soil deterioration, and therefore, potentially enhance environmental quality by curtailing on-farm run-off through better water utilization by crops.

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