Comparison of the effect of long-term tillage and crop rotation on physical properties of a soil

C. CHANG and C. W. LINDWALL

Research Station, Agriculture Canada, P. O. Box 3000, Main, Lethbridge, AB, Canada T1J 4B1. Contribution 3878831. Received 1 August 1988, accepted 9 May 1989

INTRODUCTION

Tillage systems are traditionally designed to provide weed control, incorporate crop residues, fertilizer and chemicals, and prepare a suitable seedbed. However, increased awareness of soil degradation resulting from oxidation of organic matter (Dormaar 1983), wind and water erosion, soil compaction and soil salinity has stimulated interest in developing alternatives to the traditional summerfallow-crop system employed on the Canadian Prairies. The recent development of cost-effective, non-residual herbicides has spawned considerable interest in no-till systems as an alternative to traditional intensive cultivation.

Reduced no-till systems conserve more crop residual cover, reduce soil erosion losses (Hayes and Kimberlin 1978), and save time and energy (Frye 1985) without sacrificing yield losses of cereal grains compared with conventional systems in southern Alberta (Lindwall 1978; Carefoot and Lindwall 1981) and elsewhere (Phillips 1969; Anderson 1976; Unger and Wiese 1979). However, some soil physical properties which affect crop production, such as bulk density and porosity, may be favorably or unfavorably modified by tillage (Douglas et al. 1979; Ghuman and Lal 1984; Pagliat et al. 1984; Cassel and Nelson 1985). A review of the literature indicates that the effects of tillage on the soil physical properties are related to soil type, type of tillage equipment, tillage depth, soil conditions such as moisture content at the time of tillage, and climatic conditions. If alternative tillage systems are to be adopted to the extent needed to control soil erosion effectively and improve soil and water conservation, it is necessary to examine their long-term effects on soil physical properties and potential implications for crop growth.

The objective of this study was to compare the long-term effects of summerfallow-winter wheat rotation and continuous winter wheat under conventional tillage and no-till on saturated hydraulic conductivity, saturation percentage, plant-available water-holding capacity, air-filled porosity and bulk density of soil within the tillage depth (0-60 mm) and immediately below the tilled layer (90-120 mm).

MATERIALS AND METHODS

The plots were established in 1976 on a Dark Brown Chernozemic clay loam soil at Lethbridge with crop rotations as main plots and tillage treatments as subplots in a split-plot design. The size of the subplots was 2 × 40 m. Two winter wheat rotations were established, continuous winter wheat (WW) and winter wheat-fallow (WF). The tillage treatments were conventional tillage (CT) and no-till (NT). The CT treatment (tilled at a depth of 90 mm or less) utilized a heavy-duty cultivator with 400-mm sweeps for the initial seedbed preparation, and a rod weeder and packer combination for the final seedbed preparation. The CT-WF rotation normally required 4 to 5 tillage operations for effective weed control and seedbed preparation; the CT-WW rotation required two to three operations. In the NT-WF rotation, atrazine at 0.7 kg ha⁻¹ was applied after harvest to provide residual control of weeds through part of the subsequent summerfallow season. For the remainder of the summerfallow season and prior to seeding, weed control was maintained with paraquat at 0.56-0.84 kg ha⁻¹ plus bromoxynil at 0.46 kg ha⁻¹. Later in the study, glyphosate at 0.46 kg ha⁻¹ was often substituted for paraquat. All herbicides were applied in water at 112-224 L ha⁻¹. In most years, 2.4-D at 0.56 kg ha⁻¹ was used for control of winter annual weeds in the crop and where required. Diclofop at 0.71 kg ha⁻¹ was used to control wild oats.

In the WF rotations, 55 kg ha⁻¹ of mono-ammonium phosphate (11-48-0) was applied with the seed and ammonium nitrate (34-0-0) at 90 kg ha⁻¹ was broadcast early in the spring. Similarly, in the WW rotation 55 kg ha⁻¹ of 11-48-0 was applied with the seed, and 150 kg ha⁻¹ of 34-0-0 was broadcast in the spring. Winter wheat (Triticum aestivum cv. Norstar) was seeded at a rate of 67 kg ha⁻¹ at a depth of approximately 40 mm with a high-clearance, three-rank hoe drill equipped with 20-mm wide furrow openers on a 200-mm row spacing.

Two undisturbed soil cores (35.5 mm in diameter) were collected at depths of 0-30, 30-60 and 90-120 mm from each plot of three replicates in all treatments in 1985, after seeding and after harvest. Soil cores were collected between the grain rows. Obvious wheel track areas were avoided. The 60- to 90-mm depth was not sampled because it was assumed that the tillage (tilled to 90 mm) effects on the soil at this depth interval would be similar to those on the 30- to 60-mm depth. Soil bulk density (BD), water retention at moisture potentials of 0, −20 and −1500 kPa by pressure plate (U.S. Salinity Laboratory Staff...
Plant-available water-holding capacity (PAWHC) is defined as the soil water held between the water potentials of $-20$ and $-1500$ kPa. Porosity of large size pores (large air-filled porosity, LAP) was defined as the percent volume of air-filled pores at the soil water potential of $-20$ kPa. For each depth interval, an analysis of variance was performed to test the significance of the tillage and crop main effects and the crop by tillage interaction. Differences between tillage and crop treatment means were evaluated for significance by Tukey’s test.

RESULTS

Soil texture, sandy clay loam to clay loam, was uniform throughout the study area. The sand and clay contents at each depth interval were not statistically different among the plots. However, it was observed that the sand content decreased and the clay content increased with depth. The average sand content ranged from 40.5 to 45.1%, the clay content ranged from 28.1 to 31.0%, and the silt content from 26.2 to 29.5%. The organic matter content of this soil (0 to 150 mm) was 22.4 g kg$^{-1}$.

The analysis of variance indicated that the crop-rotation-by-tillage interaction was not significant except at the 2nd depth interval. At this depth interval, the saturated HC and saturation percentage (SAT) of the soil for the CT-WF treatment (1.22 cm h$^{-1}$ and 59.3%) were significantly greater than those of the soil from both the NT-WW (0.45 cm h$^{-1}$ and 54.1%) and NT-WF (0.89 cm h$^{-1}$ and 53.4%) treatments. Soil BD for NT-WW (1.32 Mg m$^{-3}$) was significantly greater than that of the soil from the CT-WW (1.28 Mg m$^{-3}$) and CT-WF (1.24 Mg m$^{-3}$) treatments. The porosity (LAP, pore radius greater than 7.44 μm) for the soil from CT-WF (29.9%) was significantly greater than that of soil from NT-WF (23.2%).

Even though the treatment effects were not statistically significant in other depth intervals, similar trends were found for these properties.

The BD values at 30 to 60 mm (depth 2) over all treatments were significantly higher and the SAT values were significantly lower in the spring than in the fall. The PAWHC was significantly greater in the spring than in the fall for the 0- to 30- and 60- to 90-mm depths (depths 1 and 3). The other properties (Table I) were not significantly different between the spring and the fall samples.

The effects of crop rotations on the measured soil physical properties were mostly nonsignificant (Table II). Only SAT at depth 1 and HC at depth 2 were significantly greater in WF than in WW. However, similar trends for those two properties were found for the other two depth intervals. The tillage effects on the soil properties measured were more evident than the crop rotation effects, especially in the tillage zone. The BD was smaller for the soil with NT than with CT in the 1st depth interval; however, the result reversed at the 2nd depth interval (Table III). The HC and SAT of CT were greater than that of NT at the 2nd depth interval. The CT treatment, cultivated to a depth of 90 mm or less, and NT did not affect the soil properties studied differently in the 90- to 120-mm depth.

There was visible evidence that deposition of sediment had occurred on the west side of the NT plots as a result of erosion from neighboring fields.

DISCUSSION

Evidently, the machinery traffic associated with tillage operations did not affect the soil properties studied at the 90- to 120-mm depth. The soil compaction problems reported by others (Campbell et al. 1974; NeSmith et al. 1987), where the soil was cultivated under semi-humid or humid climatic conditions, were not evident in this study. Furthermore, compaction curves of Larson et al. (1980) showed that the virgin compaction increased with increasing soil moisture content in the potential range of $-100$ to $-5$ kPa. In our study, the average soil moisture content rarely approached $-20$ kPa at the times of tillage. If the soil immediately below the tillage depth had been compacted from tillage, the freezing and thawing cycles during the winter could have alleviated some of the effects (Krumback
The actions of frequent freezing and thawing cycles under the Chinook conditions of southern Alberta (Longley 1967; Grace 1987) could be the reason that the measured physical properties of the surface 30 mm were virtually unaffected by tillage treatment, even under NT conditions. Tillage with the heavy-duty cultivator should have loosened the soil, but the final seedbed preparation with the rod-weeder and packer combination would have re-compact ed the surface soil layer. As a consequence, the bulk density of the surface layer of soil under CT was greater than that of soil from the NT plots. Also, the higher porosity of large pores under CT compared with that of soil from the NT plots. Tillage with the rod-weeder and packer combination would have loosened the soil, but the final seedbed preparation with the rod-weeder and packer combination would have re-compact ed the surface soil layer. As a consequence, the bulk density of the surface layer of soil under CT was greater than that of soil from the NT plots. Also, the higher porosity of large pores under CT compared with that of soil from the NT plots.

The effects of tillage on selected soil physical properties such as HC, BD, SAT, and LAP were more evident at the 30- to 60-mm depth than at the 0- to 30-mm and 90- to 120-mm depth intervals. The tillage operation loosens the soil in the 0- to 90-mm depth but final seedbed preparation and packing do not compact the 30- to 60-mm layer to the BD level of that observed with NT for this layer. Therefore, the soil from the 30- to 60-mm layer from the CT plots had higher HC and SAT and lower BD and, to a lesser degree, higher LAP and PAWHC. The higher HC of soil from the 2-yr crop rotation (WF), compared with WW, could be attributed to the greater quantities of decayed roots which created more channels for water conduction.

In conclusion, most of the significantly different effects of long-term tillage treatments were observed for the soil from the 30- to 60-mm depth. After 10 yr of NT treatments, the HC and PAWHC were significantly lower and the BD was higher at 0- to 30-mm depth than in the CT regime. However, none of the soil properties approached values that would limit crop production as indicated by the yield of winter wheat (Zentner et al. 1988) and other researchers (Jones 1983; Letey 1985). Soil physical properties in the depth of 0-30 mm and 90-120 mm (below the tillage zone) were not significantly different among tillage and crop rotation treatments in this study.

REFERENCES


