Short-term responses of soil physical properties to corn tillage-planting systems in a humid maritime climate

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Abstract

The fertile, but naturally poorly drained soils of the western Fraser Valley in British Columbia, Canada are located in an area subject to about 1200 mm of rainfall annually. These soils were under intensive conventional tillage practices for years, which contributed to their poor infiltrability, low organic matter, and overall poor structure. Development of tillage practices that incorporate winter cover crops and reduce traffic in spring is required to reduce local soil degradation problems. The objective of this study was to determine short-term responses of soil physical properties to fall and spring tillage (ST) and fall and no spring tillage (NST) systems, both using spring barley (Hordeum vulgare L.) and winter wheat (Triticum aestivum L.) as winter cover crops. Field experiments were conducted for 3 years following seeding of the winter cover crops in fall 1992 on a silty clay loam Humic Gleysol (Mollic Gleysol in FAO soil classification). Average aeration porosity was 0.15 m$^3$ m$^{-3}$ on NST and 0.22 m$^3$ m$^{-3}$ on ST, while bulk density was 1.22 Mg m$^{-3}$ on NST and 1.07 Mg m$^{-3}$ on ST at the 0–7.5 cm depth. Neither of these two soil properties should limit seedling and root growth. After ST, mechanical resistance was consistently greater for 500–1000 kPa in NST than in ST, but never reached value of 2500 kPa considered limiting for root growth. The NST system did not increase soil water content relative to ST, with soil water contents being similar at 10 and 40 cm depth in all years. In 2 out of 3 years NST soil was drier at the 20 cm depth than was ST soil. Three years of NST did not result in a significant changes of aggregate stability relative to ST. This experiment showed that limiting tillage operations to the fall did not adversely affect soil physical conditions for plant growth in a humid maritime climate. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

The development of conservation tillage was initiated in subhumid to semi-arid regions of North America to prevent significant losses of soil and water caused by conventional tillage (Phillips et al., 1980; Allmaras and Dowdy, 1985; Dick et al., 1991). As a result, conservation tillage practices generally increase concentrations of crop residues at the soil surface and exclude primary tillage operations on an annual basis. The Conservation Technology Information Center (1984) defined conservation tillage as any...
A tillage system that conserves soil water, reduces soil erosion, and leaves at least 30% of the soil surface covered with residues after a main crop is planted. In the southwestern British Columbia (BC) and the US Pacific Northwest where rainfall is abundant and the accumulation of degree-days in summer is limited by the cooling effect of the ocean, conservation tillage practices designed for continental climates cannot be applied directly. Carter (1994) working on the Canadian Atlantic coast described suitable conservation tillage for humid regions as one that provides a continuum of live cover through the winter, some degree of residue incorporation, and efficient establishment of a main crop. Similar criteria for conservation tillage for the Canadian Pacific coast have not been established. This work is an attempt at developing an appropriate conservation tillage system for sweet corn (Zea mays L. saccharata Sturt.) production in the western Fraser Valley of BC, Canada.

The western Fraser Valley is located in the southwest corner of BC between Vancouver and the US border. Its farmland is mostly on the Fraser River delta near the Pacific Ocean. The western Fraser Valley is suitable for a wide range of crops due to its mild maritime climate, one of the longest frost-free periods in Canada, fertile medium textured soils, and flat topography. This region is characterized by fertile medium textured soils, flat topography, large amounts of winter rainfall and naturally poorly drained soils. Conventional tillage, which is prevalent in this region, consists of primary operations (moldboard plowing, disking, and subsoiling) executed in fall and spring and secondary operations (chiseling and packing) executed repeatedly (as often as 15 passes) in spring. This particular combination of climate, soil, and tillage characteristics makes this prime agricultural area especially vulnerable to compaction and structural degradation (de Vries, 1983).

There are two main reasons for excessive soil compaction in this region. First, over 850 mm of rain falls on bare soils from October to April, degrading surface structure and resulting in ponding, which delays soil drying in spring. Second, spring tillage and planting occur regularly on soils too wet to withstand traffic without causing compaction at depth. As a consequence, the western Fraser Valley soils are compacted, have inadequate surface drainage, poor infiltrability, and poor soil structure (de Vries, 1983; Temple, 1992). A study by Hermawan and Bomke (1996) showed that badly degraded soils of the western Fraser Valley had a poor surface soil structure as indicated by 1.1 mm mean weight diameter (MWD) and 63% of total soil aggregates present in the smallest (<1 mm) size fraction when measured in summer prior to a restoration program.

Development of an appropriate tillage system which is less intensive (Carter et al., 1990; Carter, 1994) and which incorporates a winter cover crop (Mitchell and Teel, 1977; Eckert, 1988; Allmaras et al., 1991) could minimize the western Fraser Valley soil degradation. Therefore, an appropriate conservation tillage-planting system might consist of fall tillage, used to facilitate soil drainage during winter and spring, combined with the seeding of a winter cover crop, and no spring tillage. To test if Carter’s requirements for residue incorporation and live winter cover crop for conservation tillage in Atlantic Canada are also valid for the Pacific coast, a tillage system which includes fall tillage only was compared with another system which includes both fall and spring tillage. Two winter cover crops, spring barley (Hordeum vulgare L.) and winter wheat (Triticum aestivum L.), were part of both tillage systems. Spring barley does not survive the first killing frost and protects the soil surface as a dead mulch. Winter wheat, on the other hand, survives the winter providing living mulch until corn planting time and requires killing in spring either mechanically or chemically. Therefore, the specific objective of this study was to determine short-term responses of soil physical properties to two tillage systems, with and without spring tillage, with winter wheat and spring barley cover crops.

2. Materials and methods

2.1. Site description

Field experiments were conducted from 1993 to 1995 in the Municipality of Delta, BC (49°05’N, 123°10’W) on a tile-drained silty clay loam Humic Gleysol (Mollic Gleysol in FAO soil classification). The 0–45 cm soil layer contains on an average 600, 270, and 130 g kg\(^{-1}\) of silt, clay, and sand, respectively. The region has an elevation of 2 m above sea level and slopes of less than 2% (Luttmerding, 1981).
The climate is humid, temperate with a mean annual air temperature of 9.9°C, an average annual precipitation of 1167 mm, and a growing season (May–August) mean precipitation of 182 mm (Environment Canada, 1998).

Two tillage-planting systems using either of two cover crops (spring barley cv. Ladner common No. 1 and winter wheat cv. Monopol) were evaluated over the 3 years. The experimental design was a randomized, complete block design with four replications and four treatments. The treatments were applied to the same area each year.

The first tillage treatment included fall tillage and no spring tillage (NST) where fall tillage consisted of subsoiling to a depth of 30 cm followed by diskng twice to a depth of 7.5 cm in 1992 and 1994, and diskng twice to a depth of 25 cm in 1993. The NST did not include any soil disturbance in spring apart from corn planting operations using a modified four-row no-till drill. The second tillage treatment included both fall and spring tillage (ST) as is traditionally done in the western Fraser Valley. The ST consisted of fall operations similar to those in the NST treatment in addition to considerable spring cultivation, which included diskng twice to a depth of 15 cm and diskng five times to depth of 7.5 cm.

Cover crops were seeded on both NST and ST treatments with a no-till drill. Seeding of the cover crops was done on September 1992, 1993, and 1994 at a rate of 100 kg ha\(^{-1}\) in 15 cm width rows. Winter wheat and the few remaining surviving plants of spring barley were sprayed with 5 l ha\(^{-1}\) glyphosate ([N-(phosphonomethyl) glycine] and 1 l ha\(^{-1}\) 2,4-D [2,4-Dichlorophenoxyacetic acid] 1 month before corn planting. After corn planting, spring barley residues covered 36% of the soil in the NST and 3% in the ST, while winter wheat residues covered 61% of the soil surface in the NST and 26% in the ST. Three-year average of the amount of residues left at the soil surface before ST was 2.2 Mg ha\(^{-1}\) on ST and 2.9 Mg ha\(^{-1}\) on NST treatment.

Sweet corn (hybrid “Jubilee”) was planted at a 3 cm depth, on 18, 7, and 15 May in 1993, 1994, and 1995, respectively. The row spacing was 0.76 m in 1993 and 1995 growing seasons resulting in a plant population of 87 000 plants ha\(^{-1}\), while in the 1994 growing season, the row spacing was 1 m and the plant population was 67 000 plants ha\(^{-1}\). The plot size was 15×9 m\(^2\).

2.2. Sampling and analyses

Aeration porosity and bulk density were determined by the core method (Blake and Hartge, 1986). Intact soil cores (7.3 cm diameter and 7.5 cm length) were taken from 0 to 7.5 cm depth from all plots before ST (25 April 1994 and 23 April 1995) and after ST (26 August 1993, 17 August 1994, 1 June, 15 July, and 29 July 1995). One soil core was taken per plot. Soil cores were weighed, then progressively saturated in a container with tap water for 12 h. After saturation, the cores were weighed and placed on a tension table, which contained a tension medium of silicon carbide sand (grit 400). Aeration porosity, i.e., soil pores having diameter >50 \(\mu m\), was determined on a tension table set at 6 kPa of matric suction (Danielson and Sutherland, 1986). Cores were dried for 24 h at 105°C and soil bulk density was determined as the mass of dry soil per volume of field-moist soil.

A hand-pushed 13-mm diameter cone (30°) penetrometer with data logger (Agridry Rimik PTY Ltd., Toowoomba, Qld, Australia) was used to measure soil mechanical resistance to the 30 cm depth, at intervals of 1.5 cm. The soil mechanical resistance was measured before ST (29 April 1994 and 23 April 1995) and after ST (1 June 1994 and 1 June 1995). Wheel traffic patterns were not strictly maintained from year to year, hence three profiles were randomly recorded per plot without a regard to wheel tracks. Since the mechanical resistance is strongly affected by the soil water content at the time of measurement, the mechanical resistance was corrected to a single soil water content using the method proposed by Busscher and Sojka (1987). This method applies a logarithmic empirical relationship among bulk density, gravimetric water content, and mechanical resistance allowing comparisons of absolute mechanical resistance independent of the original soil water content. Corrections were adjusted to a reference water content of 0.33 kg kg\(^{-1}\), an average soil water content for all measurements of soil mechanical resistance.

Soil water content was measured with a neutron meter (CPN 503DR Hydroprobe, using a 50 mCi \(^{241}\)Am–Be source). One access tube was installed per plot to a depth of 80 cm. Measurements employing the neutron probe started on 4 June 1993, 19 May 1994, and 16 May 1995. Measurements were taken as...
30 s counts obtained at 10, 20, and 40 cm depths at weekly intervals through the growing season at two locations within each plot.

Soil aggregate stability samples were taken from 0 to 5 cm depth before ST (21 April 1994 and 30 April 1995) and after ST (1 June, 7 July, 17 August, and 19 October, 1994, and then on 15 May, 1 and 15 June, 28 July, and 11 October, 1995). Three soil subsamples were taken randomly within each plot and mixed to make a composite sample. Samples were transported to the laboratory in a closed, plastic containers and stored at 4°C until analysis. The soil structural stability was assessed using a variation of the wet sieving method (Yoder, 1936). Field moist samples were sieved using a 6 mm sieve and collected on a 2 mm sieve. The pre-sieved 2–6 mm moist sample (of about 10 g) was placed on the top of a nest of sieves with openings of 2.00, 1.00, and 0.25 mm and wetted in a humidifier for 20 min to minimize disruption caused by air trapping. This was done immediately before wet sieving. Wet sieving was performed for 10 min in a motor-driven mechanical device with a vertical stroke of 2.5 cm at a rate of 30 strokes per minute. The motion of the system had both a vertical stroke and an oscillating action through an angle of 30°. After the sieves were removed from the water the proportion of material retained on each sieve was oven dried at 105°C for 24 h, weighed, and expressed as a percentage of the total soil. The results were expressed as the MWD, which represents the sum of the mean diameter of each size fraction ($D_i$) and the proportion of the sample weight occurring in the corresponding size fraction ($W_i$) (Van Bavel, 1949). The summation was carried out over all four size fractions, including the one that passed the 0.25 mm sieve ($\text{MWD} = \sum_{i=1}^{4} W_i D_i$). Corrections were made for the sand fraction retained on each sieve to avoid biased interpretations of water stable aggregates.

2.3. Statistical analyses

Data were analyzed separately for each sampling date and each depth as a $2^2$ factorial experiment in a randomized, complete block design involving two tillage systems, two cover crops, and four replications. The general linear model procedure in the SAS package (SAS Institute, 1990) was used.

3. Results and discussion

3.1. Aeration porosity and bulk density

Samples for aeration porosity and bulk density measurements were taken five times during the summers of 1993, 1994 and 1995. There was no significant difference between tillage treatments in the first year, but ST aeration porosity was higher than in NST in three of the four samplings executed in the second and third years. On these three dates, average ST aeration porosity was 50% higher than in NST with an average aeration porosity of 0.22 m $m^{-3}$ on ST and 0.15 m $m^{-3}$ on NST (Fig. 1a). Accordingly there was no significant difference in bulk density due to

![Fig. 1. (a) Aeration porosity, and (b) bulk density, under NST and ST systems during 1993–1995 seasons. Error bars represent standard error of the mean (n=8) and they are shown only on means that are significantly different at $p<0.05$.](image-url)
tillage in the first year, but there were significant differences in three of the four measurements done in the second and third years (Fig. 1b). On these three dates, average bulk density on NST was 14% higher than on ST with 1.22 Mg m$^{-3}$ for NST and 1.07 Mg m$^{-3}$ for ST.

There was a significant difference in aeration porosity due to cover crops in three of the five summer samplings in the first and third years with spring barley resulting in 25% higher aeration porosity relative to winter wheat. On average, aeration porosity with the spring barley cover crop was 0.19 m$^{-3}$ while it was 0.15 m$^{-3}$ on winter wheat treatment. There was a significant difference in bulk density due to cover crops in two of the five summer samplings in the first and third years. On these two dates, bulk density was 10% higher on winter wheat than on spring barley treatment with winter wheat resulting in an average bulk density of 1.29 and 1.17 Mg m$^{-3}$ for spring barley.

Although aeration porosity was lower with NST than with ST and with spring barley than winter wheat, it was still above 0.10 m$^{-3}$, a commonly cited critical value limiting for root growth (Greenwood, 1975; Greenland, 1981). When data from the five different sampling dates were combined to relate bulk density and aeration porosity a critical aeration porosity of 0.10 m$^{3}$ m$^{-3}$ corresponded to bulk density of 1.33 Mg m$^{-3}$ (data not shown) indicating that bulk density values obtained on both tillage systems and both cover crops were below the potentially root restricting bulk density (Fig. 1b).

The temporal variability of bulk density measurements during the first 3 years of this experiment was larger with ST than with NST for both cover crops (Fig. 2a and b). The range of variation for ST is 0.25 Mg m$^{-3}$ with spring barley and 0.24 Mg m$^{-3}$ with winter wheat, while it is only 0.10 and 0.17 Mg m$^{-3}$ for NST. Therefore, both the mean and the variance of bulk density were affected by the tillage systems. Larson and Pierce (1994) associate long-term sustainability with stability of a system for agriculture management. One way of looking at stability is to measure the range of variation of a property with time. Bulk density measurements indicated such stability to be larger with NST than ST as early as within the first 3 years of implementation (Fig. 2a and b).

### 3.2. Mechanical resistance

In 1994 and 1995 ST mechanical resistance at the 0–15 cm depth was lower than before ST, while mechanical resistance at the 15–30 cm depth did not vary much (Fig. 3). Mechanical resistance on NST treatment remained for the most part unchanged in 1994 (Fig. 3a and b), while the whole profile did consolidate from April to June in 1995 (Fig. 3c and d). In both years, after ST, NST mechanical resistance was significantly higher than ST mechanical resistance in the top 15 cm of the profile (Fig. 3b and d). In 1995, mechanical resistance was also greater in NST than in ST at the 15–30 cm depth (Fig. 3d). Before ST in 1995, mechanical resistance values were similar in both treatments (Fig. 3c), indicating that the 1994 fall
Fig. 3. Mechanical resistance under NST and ST systems (a) before ST in April 1994; (b) after ST in June 1994; (c) before ST in April 1995; and (d) after ST in June 1995. Error bars represent standard error of the mean ($n=48$) and they are shown only on means that are significantly different at $p<0.05$.

Fig. 4. Seasonal variation of soil water content under NST and ST systems. Error bars represent standard error of the mean ($n=8$).
primary tillage operations led to similar conditions in the two treatments. It should be noted, however, that all mechanical resistance values measured either before or after ST were under 2500 kPa, the value considered as limiting for root growth (Greacen et al., 1969; Busscher et al., 1986). Cover crops had a significant effect on mechanical resistance only at 1.5 and 7.5 cm depths in April and June 1995 when mechanical resistance was greater on spring barley than on winter wheat treatment.

3.3. Soil water content

Overall soil water contents, measured at 10, 20, and 40 cm depths, were relatively high (Fig. 4), reflecting the local combination of Gleysolic soil and humid, maritime climate. Cover crops had no effect on soil water content at any depth of measurement and tillage did not affect soil water contents at 10 and 40 cm depths (Fig. 4). At the 20 cm depth, NST had drier soil than did ST during 1993 and 1995 (Fig. 4). These differences were most likely of little significance for corn growing conditions, since soil water contents were still high.

3.4. Aggregate stability

Aggregate stability was measured 11 times during the second and third years of this study. Tillage effects were significant only in two of the 11 samplings, i.e., on 15 June and 11 October, 1995 (Fig. 5a). Cover crop effects were significant in only four of the 11 samplings and did not maintain a consistent trend (Fig. 5b).

Improvement in aggregate stability could not be demonstrated most likely because both tillage treatments involved fairly intensive tillage operations. Both NST and ST treatments were preceded by intensive fall tillage. In addition, the amounts of spring barley and winter wheat residues observed in this study were relatively low compared with amounts of residues left by other types of cover crops grown in this region. For example, annual ryegrass (Lolium multiflorum Lam.) which leaves about 8 Mg ha⁻¹ of residues has been shown to rapidly improve soil structure in similar soils of the western Fraser Valley (Hermawan and Bomke, 1997).

4. Conclusions

Aeration porosity was lower and bulk density higher on NST than ST, but both properties did not reach levels that should be limiting for seedling and root growth. Temporal variability of NST bulk density was consistently less than that of ST indicating short-term improvement in soil stability for water storage and drainage. Soil mechanical resistance reflected the type and depth of ST applied. Both tillage-planting systems had a mechanical resistance below the root-limiting critical value of 2500 kPa. The NST system did not increase soil water content relative to ST. On the contrary, in 2 out of 3 years soil was drier at 20 cm depth on NST than ST. Three years of NST did not
result in a significant change of aggregate stability relative to ST. The NST tillage-planting system which included low to moderate amounts of a living or a dead mulch and which limited tillage to fall provided adequate soil physical conditions for plant growth on medium textured soils of the humid Canadian Pacific coast.

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