Water-stable aggregation and organic matter in four soils under conventional and zero tillage

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Franzluebbers, A. J. and Arshad, M. A. 1996. **Water-stable aggregation and organic matter in four soils under conventional and zero tillage.** Can. J. Soil Sci. **76**: 387–393. Zero tillage management reduces soil exposure and disturbance and, therefore, may improve soil aggregation and organic matter sequestration under some environments. We determined the distribution and **soil organic C (SOC)** content of five **water-stable aggregate (WSA)** classes at depths of 0–50, 50–125, and 125–200 mm in a loam, a silt loam, a clay loam, and a clay soil managed for 4–16 yr under **conventional shallow tillage (CT)** and **zero tillage (ZT)** in the Peace River region of northern Alberta and British Columbia. Macroaggregation (>0.25 mm) and **mean weight diameter (MWD)** were greater under ZT than under CT in coarse-textured soils at a depth of 0–125 mm. Under CT, macroaggregation and MWD increased with increasing clay content, thereby reducing the potential of ZT to improve these properties in soils with high clay content. Concentration of SOC tended to be greatest in macroaggregates and lowest in microaggregates of coarse-textured soils, but was not different among WSA classes of fine-textured soils. Soil organic C content of macroaggregates under ZT was 0.34, 0.40, 0.62, and 0.16 kg m^{-2} greater than under CT at a depth of 0–200 mm in the loam, silt loam, clay loam, and clay soil, respectively. Our results suggest that implementation of ZT in this cold semiarid climate can quickly improve WSA of coarse-textured soils and potentially increase SOC sequestration, albeit more slowly than in warmer more humid climates, when macroaggregation is improved.

Key words: Aggregation, soil organic matter, soil texture, tillage

Franzluebbers, A. J. et Arshad, M. A. 1996. **Agrégation hydrostable et teneur en matière organique dans quatre sols conduits en régime de travail classique et en semis direct.** Can. J. Soil Sci. **76**: 387–393. La culture sans labour, ou semis direct, diminue l'exposition du sol et sa perturbation. De ce fait, elle peut, dans certaines conditions environnementales, améliorer la formation d'agrégats et l'immobilisation de la matière organique. Nous avons déterminé la répartition de cinq classes d'agrégats stables à l'eau (ASE) et leur teneur en C organique (COS) dans les tranches de profondeur de 0–50, 50–125 et 125–200 mm. L'étude portait sur quatre types de sol de la région de la Rivière-de-la-Paix dans le nord de l'Alberta et de la Colombie-Britannique: un loam typique, un loam limoneux, un loam argileux et un sol argileux, conduits pendant des périodes allant de 4 à 16 ans, en régime de travail superficiel classique (TC) et en culture sans labour (SD). La formation de macroagrégats (> 0,25 mm) et le diamètre pondéral moyen des particules étaient plus importants en régime SD qu'en régime TC dans les sols à texture plus grossière, dans la tranche de profondeur de 0 à 125 mm. En régime TC, la proportion de macroagrégats et le DPM augmentaient avec la teneur en argile du sol, réduisant du fait même la possibilité pour le régime SD d'améliorer ces propriétés dans les sols à forte teneur en argile. Les concentrations de C organique étaient généralement plus fortes dans les macroagrégats et plus basses dans les microagrégats des sols à texture plus grossière, mais ces différences n'apparaissaient pas entre les classes d'ASE des sols à texture fine. Dans la tranche de profondeur de 0 à 200 mm, la teneur en C organique des macroagrégats conduits en régime SD était, respectivement, de 0,34, 0,40, 0,62 et 0,16 kg m^{-2} plus forte qu'en régime TC dans le loam limoneux, le loam argileux et l'argile. Il ressort de nos observations que la pratique du SD dans cette zone de climat semi-aride froid peut rapidement améliorer la formation d'agrégats stables à l'eau dans les sols à texture relativement grossière. Par ailleurs, là où elle améliore la formation des macroagrégats, elle pourrait également accélérer la séquestration du C organique du sol, encore que plus lentement que sous les climats plus chauds et humides.

Mots clés: Agrégats, matière organique du sol, texture du sol, travail du sol

Aggregation is important in protecting soils from the destructive forces of water and wind erosion, which can deteriorate soil hydrologic and nutrient cycling properties leading to reduced production potential and environmental degradation. Cultivation of native grassland soils has resulted in 25–50% reduction in macroaggregation (>0.25 mm diam.) and SOC (Elliott 1986; Gupta and Germida 1988). Loss of SOC with cultivation appears to be linked to the destruction of macroaggregates (Tisdall and Oades 1982; Elliott 1986). Soil organic C sequestration is also important in reducing atmospheric CO_2 accumulation that contributes to global warming and in improving soil quality for sustained agricultural production. Successful development of land management strategies to improve soil quality in previously cultivated and degraded soils, therefore, requires an understanding of biogeochemical processes of accumulation and compartmentalization of SOC.

Zero tillage management generally improves soil aggregation (Carter 1992; Beare et al. 1994), although the effect has been relatively small or non-existent in some soils

Table 1. Site and experimental conditions of the four field studies

Property	Donnelly loam	Donnelly silt loam	Hythe clay loam	Falher clay
Location	55°42′N, 120°10′W	55°46′N, 120°21′W	55°11′N, 119°2′W	55°43′N, 118°41′W
Soil classification (CSSC)	Gray Luvisol	Gray Luvisol	Gray Luvisol	Solodized Solonetz
Soil classification (USDA)	Coarse-loamy, mixed, frigid Typic Cryoboralf	Fine-loamy, mixed, frigid Typic Cryoboralf	Fine, montmorillonitic, frigid Mollic Cryoboralf	fine, montmorillonitic, frigid Typic Natriboralf
Clay (%, 0–200 mm depth)	18	28	37	63
Silt (%, 0–200 mm depth)	46	51	41	31
pH (1:2, soil:water)	6.6	5.5	6.7	5.7
Initiation of tillage regime	1988	1979	1991	1989
Crop sequence (previous crop to sampling in 1995 is underlined)[z]	*Wheat*–canola–barley	*Barley*	*Barley*–canola–barley	*Barley*–fallow-canola-wheat
Experimental design	Paired plots in adjacent fields	Paired plots in adjacent fields	Randomized, block	Randomized, block
Plot size (m)	20 × 50	20 × 50	3 × 15	12 × 39
Replications	4	3	4	4

[z]Barley (*Hordeum vulgare* L.), canola (*Brassica campestris* L.), and wheat (*Triticum aestivum* L.).

(Hamblin 1980; Weill et al. 1988). Increased aggregation with ZT may be related to increased SOC (Carter 1992), although only a portion of the SOC may be responsible for maintaining water-stable aggregation (Chaney and Swift 1984). Zero tillage is gaining popularity in the Peace River region of northern Alberta and British Columbia because of concerns about soil erosion, water conservation, and decreasing margin of profit with CT. This region has been cleared of forest vegetation for less than 60 yr. However, the response of soil aggregation and SOC sequestration to ZT management in these relatively thin, forest-derived soils has not been adequately examined.

Soil aggregation is most commonly determined with a wet-sieving procedure using either field-moist soil or air-dried soil that is wetted slowly or rapidly (Yoder 1936; Kemper and Rosenau 1986). Greater differences in WSA distribution between native grassland and long-term cultivation were found when air-dried soil was slaked (i.e., rapidly rewetted) rather than capillary wetted (i.e., slowly rewetted) (Elliott 1986). Slaking resulted in slightly less macroaggregation than when capillary wetted, but both methods provided similar relative differences among treatments and soils (Elliott 1986; Beare and Bruce 1993). Slaking simulates rainfall impact after dry periods common to semiarid environments and also reflects the potential disruption of aggregates at a higher level of stability than slow wetting.

Our objectives were to determine 1) whether distribution of SOC in WSA classes was similar among soils varying in texture subjected to CT and ZT and 2) the vertical extent of potential changes in WSA with adoption of ZT.

MATERIALS AND METHODS

Soils managed under CT and ZT for 4–16 yr were collected from four locations in northern Alberta and British Columbia in late April to early May of 1995. Details on location, soil, crop management, and experimental design are listed in Table 1. Mean annual temperature is 1–2°C and mean annual precipitation is 450–500 mm. Conventional tillage consisted of one fall tillage with a cultivator equipped with chisels spaced at 200 mm and a working depth of 100–150 mm, followed by two cultivations (80–100 mm depth) in the spring prior to seeding. Zero tillage consisted of harrowing following harvest to evenly distribute straw and spraying glyphosate to control weeds prior to seeding. All crops were sown in mid May with a double-disc press drill in 170-mm-wide rows and harvested in September.

Soil samples consisted of eight composited soil cores per replicate (25 mm diam. core) sectioned into depth increments of 0–50, 50–125, and 125–200 mm. Cores were collected equidistantly along a diagonal transect within each plot. Soil was air-dried and gently crushed to pass a 5.6-mm screen to remove stones. Soil bulk density was calculated from an oven-dried subsample (60°C, 48 h) and volume of the coring tool (Blake and Hartge 1986). Water-filled pore space was determined from volumetric water content and total porosity (Linn and Doran 1984). Soil texture was determined with the hydrometer method at 40 s and 2 h for determination of clay+silt and clay, respectively (Bouyoucos 1962).

Water-stable aggregation was determined from 80 to 100 g of air-dried soil placed on a nest of sieves (175-mm diam.) with openings of 1.0 and 0.25 mm (Beare and Bruce 1993).

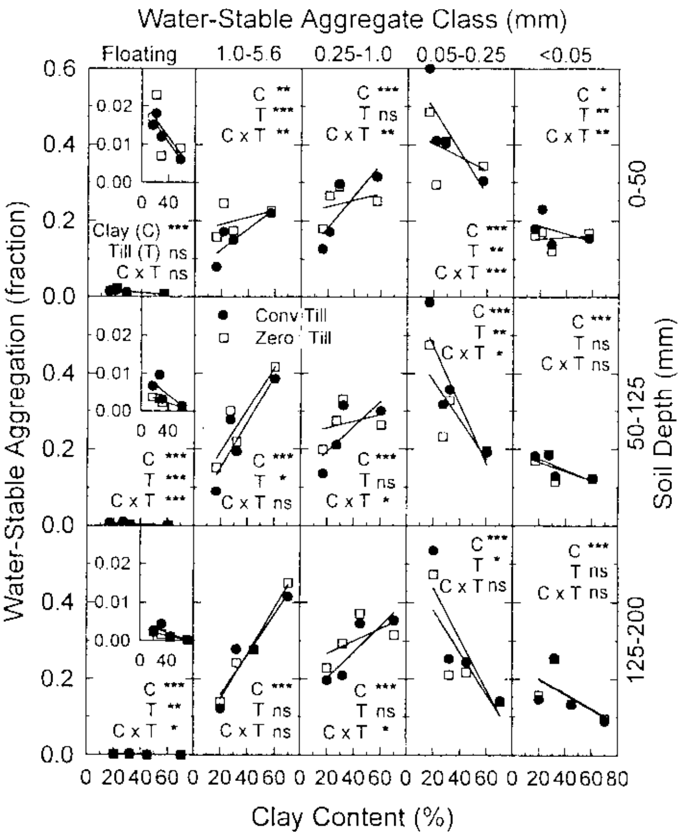

Fig. 1. Water-stable aggregation as affected by soil depth, clay content, and tillage regime. (*, ** and *** indicate significance at $P \leq 0.1$, $P \leq 0.01$ and $P \leq 0.001$, respectively; NS, not significant. Figure insets in floating class show data on a finer scale.)

Table 2. Water-filled pore space at sampling, water-stable aggregation, and soil organic C content of classes in four soils under CT and ZT to a depth of 200 mm

Water-stable aggregate class (mm)	Donnelly loam		Donnelly silt loam		Hythe clay loam		Falher clay	
	CT	ZT	CT	ZT	CT	ZT	CT	ZT
Water-filled pore space at sampling (fraction of total porosity)								
Whole soil	0.36*	0.48	0.36*	0.46	0.48**	0.59	0.73	0.75
Water-stable aggregation (kg m^{-2})								
Floating	1.7	1.5	2.1**	1.5	0.9	0.6	0.4	0.6
1.0–5.6	24.6*	37.8	58.9	62.3	47.9	53.7	85.4	92.2
0.25–1.0	39.1*	53.1	46.5*	65.4	70.1	78.4	76.9	67.0
0.05–0.25	139.4*	121.4	71.7*	55.4	68.5	68.8	46.9	48.4
<0.05	40.7	41.5	51.7	49.7	28.6	28.9	27.7	28.7
$LSD_{(P \leq 0.1)}$	12.9	15.3	5.6	20.3	8.8	5.1	8.8	14.8
Total	245.4*	255.3	231.0	234.3	216.0**	230.5	237.3	236.9
Soil organic carbon (kg m^{-2})								
Floating	0.37	0.33	0.43	0.37	0.20	0.17	0.11	0.13
1.0–5.6	0.47	0.68	1.52	1.57	1.34	1.63	2.65	3.04
0.25–1.0	1.03	1.16	1.51	1.86	2.22*	2.55	2.44	2.21
0.05–0.25	1.90*	1.59	1.54**	1.08	2.33	2.44	1.63	1.71
<0.05	0.69*	0.61	0.55*	0.43	0.59	0.54	0.87	0.88
$LSD_{(P \leq 0.1)}$	0.17	0.23	0.12	0.50	0.36	0.19	0.23	0.49
Whole soil	4.35	4.28	5.31	4.98	6.48*	7.20	8.09	8.36

*, ** indicate significance between tillage regimes at $P \leq 0.1$ and $P \leq 0.01$, respectively.

Soil was immediately immersed in water and the sieves raised and lowered (35-mm stroke length) 160 times during 10 min. Floating organic material retained within the walls of the top sieve was removed with a screen (0.125-mm openings) and placed in a drying dish. After removing sieves, water containing soil passing the 0.25-mm screen was poured over a 0.053-mm screen. Soil passing the 0.053-mm screen was allowed to settle for ≈1 h, the supernatant decanted, and pooled across the three depths for SOC determinations. Fraction of soil <0.053 mm was calculated for

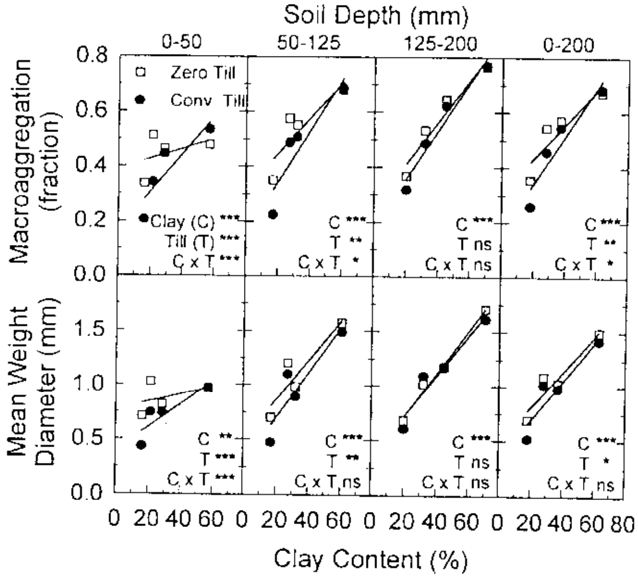

Fig. 2. Fraction of soil as macroaggregates (>0.25 mm) and mean weight diameter as affected by soil depth, clay content, and tillage regime. (*, ** and *** indicate significance at $P \leq 0.1$, $P \leq 0.01$ and $P \leq 0.001$, respectively; NS, not significant.)

each depth by difference between initial soil weight and accumulation of the other four fractions. All fractions were oven-dried (60°C, 24 h). Mean weight diameter of soil was calculated by summing the products of WSA fraction and mean diameter of WSA class, excluding the floating material (Kemper and Rosenau 1986).

Floating material was ground to pass a 1-mm screen and mineral classes were ground to pass a 0.25-mm screen. Organic C of all classes and of whole soil prior to fractionation was determined using the modified Mebius method in digestion tubes (Nelson and Sommers 1982).

Soil properties were analyzed for each soil depth with tillage regime as a split-plot within soil type using the general linear model procedure of the SAS Institute, Inc. (1990). Soil organic C concentration of WSA classes was analyzed for each soil depth and soil type with tillage regime as a split-plot within WSA class. Means and linear clay content effects were considered significant at $P \leq 0.1$.

RESULTS AND DISCUSSION

Water-Stable Aggregation

Distribution of WSA was affected primarily by clay content and secondarily by tillage regime (Fig. 1). The greatest quantity of soil was in the 0.05–0.25 mm class in the Donnelly loam, in the 0.05–5.6 mm classes in the Donnelly silt loam, in the 0.05–1.0 mm classes in the Hythe clay loam, and in the 1.0–5.6 mm class in the Falher clay (Table 2). Thus, WSA size distribution in these soils was inversely related to the particle size distribution. Montmorillonite dominates the clay fraction of these soils, and therefore, increasing clay content would be expected to increase WSA. Kemper and Koch (1966) also observed a strong increase in aggregate stability with increasing clay content.

Floating material comprised less than 3% of the total soil, with the amount decreasing with soil depth (Fig. 1). The floating class represents undecomposed and partially decomposed organic material, probably a subset of the "light fraction" with a density of <1.13 Mg m^{-3} (Meijboom et al. 1995). The quantity of floating material was greater in coarse-textured than in fine-textured soils at all soil depths (Fig. 1). Tillage regime had no effect on the amount of floating material at a depth of 0–50 mm, but at depths of 50–125 mm and 125–200 mm soil under CT contained a greater fraction of floating material than under ZT in coarse-textured soils. Crop residues were incorporated under CT to a maximum depth of 150 mm, which likely contributed to the greater fraction of floating material with CT. Lack of difference between tillage regimes in the quantity of floating material in fine-textured soils may have been due to greater participation of partially decomposed residues to WSA formation, since larger and more stable aggregates formed in fine-textured soils.

Water-stable aggregation of the 1.0–5.6 mm and 0.25–1.0 mm classes increased with increasing clay content at all soil depths (Fig. 1). At a depth of 0–50 mm, the quantity of soil in these two largest size classes was greater under ZT than under CT in coarse-textured soils, but similar between tillage regimes in fine-textured soils (Figs. 1 and 2). A greater fraction of soil in the 0.25–1.0 mm class under ZT than under CT in coarse-textured soils also occurred in the 50–125 mm and 125–200 mm depths (Fig. 1). The effect of ZT on macroaggregation (>0.25 mm) in coarse-textured soils was greatest at a depth of 0–50 mm, less at a depth of 50–125 mm, and not significant at a depth of 125–200 mm (Fig. 2). The higher degree of "native" aggregation with fine-textured soils compared with coarse-textured soils appears to have limited the potential for ZT to improve aggregation at any depth in fine-textured soils.

Differences in length of tillage comparison among soils did not appear to have confounded the results of WSA, since the change in macroaggregation due to ZT compared with CT to a depth of 200 mm on a yearly basis averaged 0.014, 0.006, 0.007, and –0.002 g g^{-1} yr^{-1} in the loam, silt loam, clay loam, and clay, respectively. At the end of 13 yr of ZT on a sandy clay loam in Georgia, the fraction of soil as macroaggregates was 0.21 greater than under CT at a depth of 0–50 mm, but only 0.05 greater than under CT at a depth of 0-150 mm (Beare et al. 1994). For a range of soil textures in Australia, the fraction of soil (0–100 mm depth) as macroaggregates was 0.05 ± 0.03 greater at the end of 3–8 yr of ZT compared with CT (Hamblin 1980). In contrast to our results concerning soil texture, aggregate stability at the end of 5 yr of ZT in Quebec was greater than under CT in four of eight observations in a clay, but in only one of eight observations in a sandy loam (Weill et al. 1988).

Greater macroaggregation with ZT compared with CT was offset by a decrease in the 0.05–0.25 mm class (Fig. 1, Table 2). At a depth of 0–50 mm, a lower fraction of soil in the <0.05 mm class under ZT than under CT in coarse-textured soils suggests that without a protective residue cover,

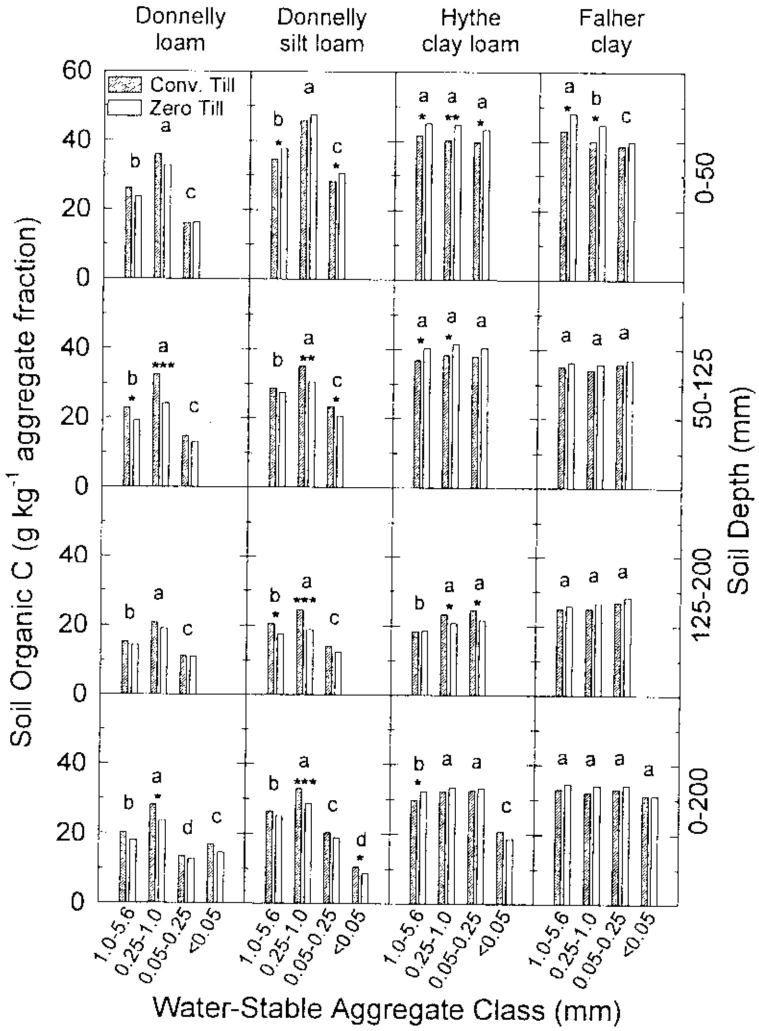

Fig. 3. Soil organic C concentration of water-stable aggregate classes as affected by soil depth and tillage regime in four soils. (Class means within a soil depth and soil type with the same letter above bars are not significantly different at $P \le 0.1$. The symbols *, ** and *** above bars indicate significance between tillage regimes within a size class, soil depth, and soil type at $P \le 0.1$, $P \le 0.01$ and $P \le 0.001$, respectively. Soil organic C of the <0.05 mm class was determined only for the 0–200 mm depth.)

surface soil aggregates were reduced to primary particles by rainfall impact and intensive drying/wetting and freezing/thawing.

Mean weight diameter exhibited a similar pattern as macroaggregation (Fig. 2). Zero tillage had the greatest impact on MWD at a depth of 0–50 mm in coarse-textured soils (up to 63% increase compared with CT) and smaller impact at a depth of 50–125 mm in all soils (mean increase of 13% compared with CT). The importance of separating soil into smaller depth increments when investigating the effect of tillage regime on aggregation is illustrated in Fig. 2. The effect of ZT on MWD diminished with depth and was only marginally significant when considering the entire 0–200 mm depth. On a fine sandy loam in Prince Edward Island, MWD at a depth of 0–50 mm under ZT was 43–53% greater than under moldboard plowing at the end of 3–5 yr (Carter 1992).

Soil Organic Carbon

SOC concentration varied mostly with WSA class and to a lesser extent with tillage regime (Fig. 3). SOC concentration decreased with depth in all WSA classes of all soils. SOC concentration of the floating material averaged 237 g kg^{-1} across soils with no significant ($P \le 0.1$) difference between tillage regimes, except in the Hythe clay loam where the SOC concentration of the floating material under ZT was 26% greater than under CT.

Soil organic C concentration of the mineral classes was greatest in the 0.25–1.0 mm class in the Donnelly loam and silt loam at all depths. Macroaggregates contained greater SOC concentration than microaggregates in these two coarse-textured soils. In the Hythe clay loam and Falher clay, SOC concentration tended to be more evenly distributed among WSA classes. Exceptions to this general trend were 1) lower SOC concentration in the <0.05 mm class compared with other classes at a depth of 0–200 mm in the clay loam and 2) greater SOC concentration of macroaggregates than microaggregates at a depth of 0–50 mm in the clay.

Generally, SOC concentration of WSA was greater under ZT than under CT primarily in macroaggregate classes and at a depth of 0–50 mm (Fig. 3). However, tillage regime had

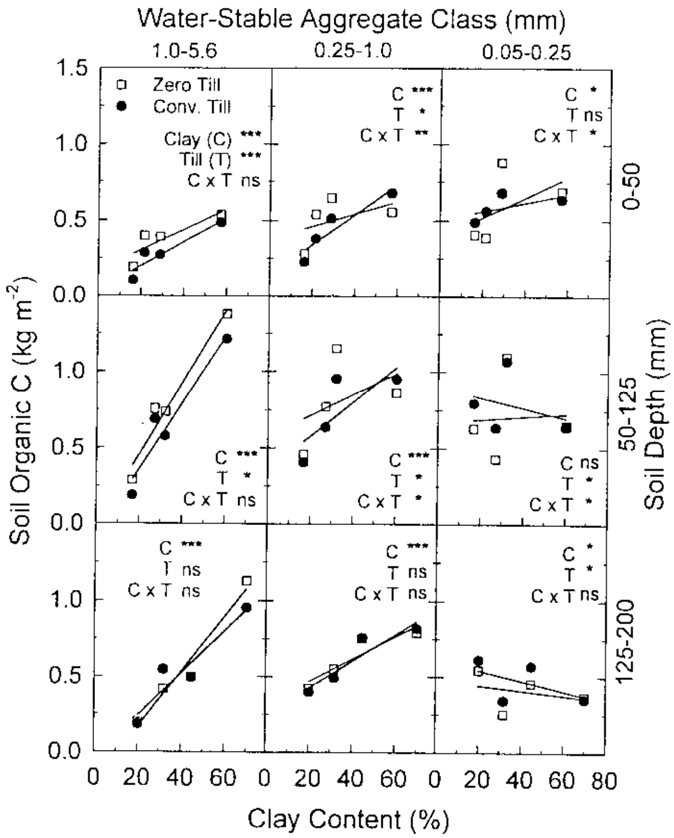

Fig. 4. Soil organic C content of water-stable aggregate classes as affected by soil depth, clay content, and tillage regime. (*, ** and *** indicate significance at $P \leq 0.1$, $P \leq 0.01$ and $P \leq 0.001$, respectively; NS, not significant.)

no effect on SOC concentration of WSA in the Donnelly loam at a depth of 0–50 mm, but SOC concentration of ZT was less than under CT in macroaggregates at a depth of 50–125 mm. Greater SOC concentration of macroaggregates under CT compared with ZT also occurred at depths of 50–125 mm and 125–200 mm in the Donnelly silt loam and a depth of 125–200 mm in the Hythe clay loam. Greater SOC concentration with CT at a depth of 50–200 mm was likely due to crop residue incorporation that contributed to WSA. Soil organic C concentration of WSA classes subjected to a slaked wet-sieving similar to our treatment was greatest in macroaggregates, least in microaggregates, and intermediate in the <0.05 mm class under both cultivation and native grassland in a loam from Nebraska (Elliott 1986). In contrast, SOC concentration in a sandy loam from Saskatchewan was greatest in the <0.10 mm class under cultivation and 0.25–0.50 mm class under native grassland and lowest in the 0.10–0.25 mm class under cultivation and >1.0 mm class under native grassland (Gupta and Germida 1988).

Our results suggest that in situ decomposition of SOC in coarse-textured soils is enhanced in the <0.25 mm classes relative to macroaggregates. Physical protection of organic matter from decomposition may occur within stable aggregates or by its adsorption to clay particles, both of which limit microbial and faunal accessability for decomposition (Tisdall and Oades 1982). Similarity in SOC concentration of the 0.25–1.0 mm class among soils, regardless of tillage regime, implies that protective mechanisms in this WSA class may have been similar, whereas divergence in SOC concentration among soils in classes <0.25 mm implies divergence in protective mechanisms. Therefore, lower SOC concentration of coarse-textured soils may have been due to greater turnover of C in the <0.25 mm classes, which was likely lower in clay content than in fine-textured soils, affording less protection of SOC from decomposition by clay adsorption. Although we did not determine the clay content of WSA classes, support for this hypothesis is available from Christensen (1986), who found that the <0.25 mm class in a sandy clay loam contained 10% less clay and 5 g kg^{-1} less SOC than whole soil, whereas in a loamy sand the <0.25 mm class contained 1.5% more clay and 4 g kg^{-1} more SOC than whole soil.

Soil organic C content of the 1.0–5.6 mm class under ZT was 0.09 kg m^{-2} greater at a depth of 0–50 mm and was 0.12 kg m^{-2} greater at a depth of 50–125 mm compared with CT averaged across soils (Fig. 4). To a depth of 200 mm, SOC content of the 1.0–5.6 mm class was an average of 0.23 kg m^{-2} greater under ZT than with CT (Table 2). Soil organic C content of the 0.25–1.0 mm class was greater under ZT than under CT only in coarse-textured soils at depths of 0–50 mm and 50–125 mm (Fig. 4). Based on the regression with clay content, a soil to a depth of 200 mm containing 20% clay would have 0.31 kg m^{-2} more SOC in the 0.25–1.0 mm class under ZT than under CT, but a soil containing 60% clay would have similar amounts of SOC under either tillage regime. Since SOC content of the whole soil was not greatly affected by tillage regime (Table 2), greater SOC with ZT in the macroaggregate fractions led to lower SOC with ZT in the microaggregate fractions in coarse-textured soils at lower depths (Fig. 4) and at a depth of 0–200 mm (Table 2).

Our results of greater SOC content in macroaggregate classes (>0.25 mm) under ZT compared with CT are in close agreement with the results obtained for a sandy clay loam in Georgia comparing 13 yr of ZT with CT (Beare et al. 1994). In that study, macroaggregates under ZT contained 0.45 kg m^{-2} more SOC to a depth of 150 mm than under CT.

Soil organic C content of the floating material was not affected by tillage, but decreased with increasing clay content (Table 2). Although the fraction of whole soil as floating material was less than 3% in all soils, it contributed 1–8% of whole-soil C, increasing with decreasing clay content. In a sandy clay loam in Georgia, the percentage of whole-soil C as floating C was only 1.1–1.4% to a depth of 150 mm (Beare et al. 1994). The SOC content of the floating material appears to have contributed more to whole-soil C in the cold, semiarid climate of western Canada than in the warm, moist climate of the southeast United States. Large climatic effects on the portion of this labile SOC pool (Hassink 1995) are likely, since the opportunities for decomposition of this labile pool in a cold, semiarid climate are probably several-fold less than in a warm, moist climate.

CONCLUSIONS

Coarse-textured, previously cultivated soils in the cold, semiarid climate of the Peace River region of northern Alberta and British Columbia could be effectively managed with ZT to improve WSA to a depth of 125 mm. Soil organic C sequestration with ZT compared with CT occurred only in the water-stable macroaggregate fractions (>0.25 mm) to a depth of 125 mm. Sequestration of SOC in macroaggregates with ZT was greater in coarse-textured soils than in fine-textured soils. However, SOC content of microaggregate fractions (<0.25 mm) was lower under ZT than under CT in coarse-textured soils. Although ZT had the greatest impact on macroaggregation and SOC accumulation within macroaggregates in coarse-textured soils, greater accumulation of whole-soil C with ZT was not realized in coarse-textured soils, likely because of more rapid turnover of C in the microaggregate fractions that afforded little clay protection. Fine-textured soils, however, may have provided more clay protection to SOC across WSA classes, such that whole-soil C tended to increase with ZT compared with CT more so than in coarse-textured soils. Zero tillage in this cold semiarid climate appears to have potentially beneficial impact on aggregation and soil water conservation, but little immediate impact on SOC.

ACKNOWLEDGEMENTS

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