Long-term Tillage and Crop Rotation Effect on Soil Aggregation

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Abstract

Tillage and cropping sequences play a key role in controlling soil aggregation. We measured water-stable aggregate (WSA), wind erodible fraction (WEF), and geometric mean diameter (GMD) for six mid to long-term (8 to 25 years) experiments comparing tillage and cropping sequences in the Brown, Dark Brown, and Black Chernozemic soils of Saskatchewan. In the coarse-textured soil, no-tillage (NT) had a higher value of WSA by 49% more than in the wheat-phase of fallow-wheat (F-W), and had a lower value of WEF by 27% less than in the fallow-phase of F-W compared with minimum tillage (MT). In the medium-textured soils, NT had a higher WAS, ranged from 17 to 38%, and a lower WEF, ranged from 37 to 64% compared with conventional tillage (CT), depending on crop rotation systems. The reduced WEF under NT in the medium-textured soils was due mainly to increased GMD. In the fine-textured soils, NT had a higher WSA, ranged from 10 to 19% compared with MT or CT, and a lower WEF by 47% compared with MT only in the heavy clay soil. Change in GMD was not detectable in the light- and fine-textured soils. Continuous cropping compared with rotations containing fallow improved soil physical properties by increasing WSA, reducing WEF in the medium and fine-textured soils, and increasing GMD only in the medium-textured soils. Of the three soil physical properties determined in this study, WSA was the most sensitive to changes in tillage and crop rotations, then WEF and the least GMD.

Introduction

Zero-tillage or minimum tillage has been shown to improve soil physical and chemical properties, reducing erosion, and thus sustaining long-term soil productivity (Tessier et al., 1990; Campbell et al., 1993a, b; Campbell et al., 1995).

Soil structure plays a key role in controlling water infiltration, and water and wind erosion. Wind erosion is known to be one of the most serious degradation processes limiting agricultural sustainability on the semiarid prairie soils (Larney et al., 1994). One of the main factors determining the severity of wind erosion is aggregate size distribution on the surface soil. Aggregate size distribution is strongly controlled by climatic processes such as freezing-thawing and wetting-drying and by management practices such as cropping systems and tillage (Campbell et al., 1993 a,b).

The presence of crops and management practices that increase crop residues tend to reduce the wind-erodible fraction and to increase the geometric mean diameter (Campbell et al., 1993a, b). Wet-aggregate stability was also increased by frequent cropping and by adequate fertilization as a result of increased production of crop residues. Summer-fallowing increased the wind-erodible fraction of soil, and decreased the geometric mean diameter of aggregates. However, Angers et al. (1993) reported that rotations had no effect on soil aggregation, and the mean-weight diameter of water stable aggregates did not vary significantly with time under the NT management, but decreased significantly under the MT and CT treatments.

The mechanism of physical enmeshment by roots is temporary and acts to stabilize macro-aggregates >250 μm in diameter (Tisdall and Oades, 1982). Many investigators have demonstrated an increase in the stability of aggregates accompanying an increase in the amount of soil organic C (Tisdall and Oades, 1982). Organic matter acts primarily to stabilize micro-aggregates <250 μm in diameter. The presence of specific stabilizing materials is often more important than the total organic matter content. For instance, polysaccharides appear to produce a transient change in aggregate stability, while the more resistant humic materials are responsible for long-term or persistent effects (Tisdall and Oades, 1982). Dehydration associated with drying or freezing appears to be a prerequisite for water-stable aggregate formation.

Conservation tillage can improve soil aggregation and reduce losses of soil organic matter that result from cultivation (Havlin et al., 1990; Carter, 1992; Weill et al., 1989). Several studies have also demonstrated that soil erodibility is reduced (Black and Power, 1965; Anderson, 1971; Tanaka, 1985; Singh et al., 1994) by increasing either crop residue cover or the size of surface soil aggregates. Although it is generally known that soil texture plays a predominant role in controlling some of soil physical properties such as water-stable aggregate, wind erodibility, and geometric mean diameter, studies of soil structure involving tillage and crop rotations under a range of soil textures are rare. This information is important in planning tillage and crop rotation strategies for improving soil structure and reducing wind erosion in the Canadian prairies. Six mid to long-term field studies involving tillage and crop rotations under a range of soil texture in Saskatchewan provided an opportunity to evaluate impacts of tillage systems, crop rotation and soil texture on WSA, WEF and GMD.

Materials and Methods

The six field experiments involved a range of soil textures, soil climates, crop rotations, and tillage systems (Table 1). All of these studies were originally designed to compare the agronomic performance of tillage systems within and between crop rotations. All experiments were relatively large plot size (350-1400

m^2), and full-size farm equipment was used for tillage and planting operations. Tillage depth was 5 to 10 cm, depending on soil conditions, tillage implements and time since last tillage. All experiments received N and P fertilizer to remove nutrient stress for average crop production levels. In-crop herbicides were used in all systems, as required to control weeds.

Rotations and tillage practices were similar for the Swinton loam (L), Sceptre clay (C) and Hatton fine sandy loam (FSL). Experimental details that are relevant to this study are briefly described. Other details of the management of experiments in the Brown soil zone are reported elsewhere (Campbell et al., 1995; Campbell et al., 1996a; Campbell et al., 1996b; McConkey et al., 1996). Two crop rotations, continuous wheat (Cont W) and fallow-wheat (F-W) were used. Each phase of F-W was presented each year. Spring wheat (*Triticum aestivum* L.) was used on the Swinton L and Sceptre C, and durum (*Triticum turgidum* L.) on the Hatton FSL. Tillage systems for these studies consisted of minimum tillage (MT) and no-tillage (NT). Pre-seeding tillage with one operation of heavy-duty cultivator equipped with sweeps and rodweeder or mounted harrow, was used for MT. For NT weeds were controlled before planting with herbicides. No-tillage fallow involved herbicides only while MT fallow used one application of broad-spectrum herbicides plus one or two operations with wide-blade cultivator or heavy-duty cultivator. A combination of insect damage and dry weather conditions resulted in severe wind erosion for MT in 1984 on the Hatton FSL (losing approximately 5 cm of soil), so NT was used on the fallow phase of MT F-W until 1988, when there was adequate residue to control erosion. Planting was performed with an offset disc press drill (Tessier et al., 1990) for NT and a conventional hoe drill for MT.

On the Melfort silt clay (SiC), three tillage systems (CT, MT and NT) under a F-W rotation were used. Each phase of the rotation was present each year. The heavy-duty cultivator equipped with sweeps was used for tillage operations on summer-fallow. In some years a rodweeder replaced one or more of the cultivation operations. The first fallow tillage operation was performed in early June with subsequent operations performed on an as needed basis usually at 2 to 3 week intervals. Treatments of NT for weed control during fallow generally received a first herbicide application in late May or early June with repeat applications as required in July and August. Tillage operation for MT was similar to that of CT, but the number of tillage operation was reduced to twice a year by substituting herbicides for some weed control.

On the Indian Head clay (C), crop systems consisted of three, 4-yr rotations. One crop rotation included 1 yr of fallow in four, fallow-spring wheat-spring wheat-winter wheat (FWWwW) while the other crop rotations were continuous cropping systems, pea (*Pisum sativum* L.)-spring wheat-flax (*Linum usitatissum* L.)-winter wheat (PWXwW) and spring wheat-spring wheat-flax-winter wheat (WWXwW))(Lafond et al., 1992). Each phase of rotations was present each year. Three tillage systems (CT, MT and NT) were used. Minimum tillage included only one tillage operation in the spring using a heavy-duty cultivator equipped with 41-cm sweeps. Cultivator tillage included fall tillage after harvest and spring tillage before seeding. In the NT system, weeds on fallow were controlled with herbicide applications. In the CT system, weed control on fallow was by mechanical means, with 2 to 4 cultivations and 0 to 3 rodweeder operations per year. Weed control on MT fallow was accomplished with herbicides and one operation with heavy duty cultivator followed by one operation with a rodweeder. Other details of the experiment can be found elsewhere (Lafond et al., 1992).

On the Elstow clay loam (CL), two crop rotations including a continuous cropping of wheat-wheat-canola (*Brassica napus* L.)-wheat-wheat-flax (WWCWWX) and a rotation containing one fallow in three years, fallow-flax-wheat-fallow-canola-wheat (FXWFCW), were used. Only one phase of WWCWWX was present each year and only three phases of the FXWFCW rotation were present each year. Tillage systems were CT and NT. Herbicides were used exclusively for weed control in the NT treatments. In the CT cropping system, tillage with a heavy-duty cultivator equipped with spikes or sweeps was performed on stubble in late fall. Early spring tillage was carried out with a cultivator equipped with mounted harrows followed by cultivating or rod weeding just prior to seeding for all CT treatments. The tillage fallow normally required three operations with a cultivator and mounted harrows, plus one or two operations with a cultivator or rod-weeder. Seeders used included a double-disc press drill, an offset double disc press drill and a narrow hoe press drill. Further experimental detail can be found (Brandt, 1992).

Soil samples were taken from the Hatton FSL, Swinton L, Sceptre C in the spring of 1994, the Melfort SiC and Indian Head C in the fall of 1994, and the Elstow CL in the fall of 1995. Soils were sampled by pressing a metal frame, 17.5 cm x 17.5 cm x 5 cm deep with a cutting edge into the soil, then digging up the frame with a spade, shaving off the cube of soil and placing it in an aluminum tray. The samples were carefully transferred to paper bags, transported to a greenhouse where the samples were air-dried for about 1 wk with careful turning.

The aggregate size distribution was determined by dry-sieving the air-dry soil using a rotary sieve as described by Chepil and Bisal (1943). This process separated the soil into six size fractions, i.e., <0.42 mm, 0.42-0.84 mm, 0.84-2.0 mm, 2.0-6.4 mm, 6.4-12.7 mm, and >12.7 mm. The wind erodible fraction (WEF) was expressed as the percent aggregates with diameters of less than 0.84 mm. Geometric mean diameter was calculated following the method of Gardner (1956), and further described by Campbell et al. (1993a). The 0.84-2.0 mm fraction by dry sieving was used to obtain 1-2 mm aggregates which were then used to determine aggregate stability by wet sieving (Kemper and Rosenau, 1986). The aggregates , without pre-wetting, were wet-sieved in distilled water for three minutes using an apparatus with a stroke length of

1.3 cm and a frequency of 35 cycles per min. The material passing through the sieve (unstable aggregates) was oven-dried at 110ºC. Coarse sand (>0.26 mm) was separated from the material remaining on the sieve by ultrasonic vibration (Kemper and Rosenau, 1986). The stable aggregates from which the coarse sand was removed were collected and oven dried. The stability of the aggregates was calculated by expressing the mass of stable aggregates as a percentage of the total.

Wet-aggregate stability, WEF and GMD were statistically analyzed for each site (SAS Institute, 1990). For the Hatton FSL, Swinton L and Sceptre C, treatment differences were separated using contrasts. Three contrasts were selected to compare (F)-W versus F-(W), Cont W versus F-W, and MT versus NT. Experimental data were analyzed using a single factor randomized complete block design for the Melfort SiC, and using a 2 x 3 factorial randomized complete block design for the Elstow CL. For the Indian Head C, a split-plot design with tillage systems as main plots and crop rotations as sub-plots was used. To find differences in main or interaction effects, the Least Significant Differences were calculated and hypotheses were tested at the $P=0.05$ level of significance. Least Significant Differences were used to separate treatment means only if the corresponding F statistic was significant.

Results and Discussion

In the Hatton FSL, NT had a higher value of WSA and a lower value of WEF compared with MT (Table 2). Within the F-W rotation, the specific phase of F-W had no significant impact on WSA, WEF or GMD. Continuous cropping only had a greater value of WSA compared with F-W. In the Swinton L, NT had an impact on soil structure by increasing WSA, reducing WEF, and increasing GMD compared with MT(Table 3). Similar effects were also observed for Cont W compared with F-W. Within the F-W rotation, only a higher value of WSA was found to associate with F-(W). In the Sceptre C, NT improved soil structural stability by increasing WSA and reducing WEF, compared with MT (Table 4). Similarly, a higher value of WSA and a lower value of WEF were associated with F-(W) within the F-W rotation. However, the difference in soil structural stability between Cont W and F-W was less obvious with an exception that Cont W increased WSA.

In the Elstow CL, NT had a higher value of WSA, and a lower value of WEF accompanied by a higher value of GMD, compared with CT (Table 5). Similarly, continuous cropping had a higher value of WSA and GMD, and a lower value of WEF, compared with the rotation containing fallow once in three years. In the Indian Head C, a higher value of WSA was found to associate with MT and NT compared with CT, and WWXwW also had a higher value of WSA compared with the rotation containing fallow once in four years (Table 5). In the Melfort SiC, NT had a higher value of WSA compared with CT.

Continuous cropping improved soil physical structural stability by increasing WSA for the Hatton

FSL, Swinton L, Elstow CL, Sceptre C and Indian Head C, compared with F-W or rotations containing fallow once in every three or four years. On the other hand, the specific phase of rotation affected soil structural stability inconsistently. For instance, within the F-W, there was a difference in WSA between F-(W) and (F)-W for the Swinton L and Sceptre C, but not for the Hatton FSL. Similarly, the specific phase within the same fallow containing rotation on the Elstow CL had no impact on soil physical structural stability.

The wheat phase of F-W had a higher value of WSA in the Swinton L and Sceptre C, and a higher value of WEF only in the Sceptre C compared with the fallow phase of the same rotation, suggesting that both WSA and WEF are dynamic and changes can be observed within a year. This difference in WSA and WEF observed within the different phase of the same rotation may have been due mainly to the presence of crop cover and root exudates, or changes in surface soil moisture regimes. The deposition of carbon from root exudates, fungal hyphae, and root hairs will increase the strength of weaker failure zones and contribute to the stabilization of macro-aggregates (Oades, 1984).

Continuous cropping or reducing the frequency of fallow in rotations contributed to significant increases in WSA for all soils, but increase in GMD and reduction in WEF were only observed on medium-textured soils. Greater improvement of the structural stability with continuous cropping was found in the coarse- and medium-textured soils. This effect of crop rotations on the soil structural stability probably reflects increased inputs of crop residues associated with continuous cropping, which is consistent with the finding of Campbell et al. (1993a,b), who reported that less frequent fallow and adequate fertilization, and use of legume green manure increased aggregate stability in similar soils.

Compared with either MT or CT, NT improved soil physical properties by increasing WSA for all soils and reducing WEF for coarse- and medium-textured soils, and increasing GMD only for medium-textured soils. Soil disturbance as a result of tillage operation may break down macroaggregates directly, or through accelerating decomposition of organic materials acting as stabilizing agents that are physically protected by macroaggregates. This is especially important during fallow because there is very limited replenishment of crop residues and root exudates over the growing season from few weeds that may grow on fallow. Conversely, during the crop year there is no excessive breakdown of macroaggregates by tillage operations during the growing season and a replenishing of stabilizing organic materials that work to re-form macroaggregates.

Tillage is normally carried out to control weeds, incorporate crop residues and prepare a loosened seedbed. Soil will deform or fail in response to tillage by brittle failure, compressive failure, or tensile failure (Kay, 1990). As a result, tillage may have large impact on the structural stability at the scale of macroaggregates (Tisdall and Oades, 1980). The extent of change in soil structural stability in response to tillage operations may depend on tillage frequency, cropping sequences, and soil texture.

Tillage causes sorting of aggregates, with smaller aggregates tending to sink to the bottom of the tilled layer and the larger ones tending to rise to the surface. As a consequence, the distribution of aggregates can be modified. Tillage diminishes the continuity of pores within the tilled layer, and between the tilled and untilled zones, can create a compacted zone at the base of the tilled layer and enhances mineralization of organic stabilizing materials. Tillage reduces the amount of crop residues on the soil surface, thus enhancing the susceptibility of the surface to erosion.

The data for the Indian Head C and Melfort SiC have shown that changes in tillage frequency from CT to MT were relatively ineffective in improving WSA, reducing WEF, and increasing GMD. Significant improvement in soil structural stability could be readily observed when comparing NT with MT, indicating that a relatively small soil disturbance with MT can cause significant reduction in soil structural stability on the prairie soils. Cropping sequences can also affect soil structural stability. For instance, NT increased WSA in the wheat-phase of F-W, reduced WEF in the fallow-phase of F-W compared with MT, but had no effect on either WSA or WEF in the Cont W compared with MT in the Hatton FSL soil. Tillage impact on the soil structural stability was less pronounced in the Cont W than in the F-W. This may have been resulted from increased crop productivity, enhanced crop residues returned to the soil in the Cont W, thus alleviating tillage-induced soil structure stability damage, at least to some extent.

Soil texture plays an important role in response to tillage operations and controlling soil structural stability. In the coarse-textured soil of Hatton FSL, NT increased WSA by 16%, and reduced WEF by 15%, compared with MT. In the medium-textured soils of Swinton L and Elstow CL, NT increased WSA on an average of 21%, and reduced WEF, on an average of 38% compared with either MT or CT. The reduced WEF under NT in the medium-textured soils was due mainly to the increased GMD. In the fine-textured soils of Sceptre C, Melfort SiC and Indian Head C, NT only increased WSA by 12% compared with MT or CT, with an exception that NT also reduced WEF by 44% for the Sceptre C. Greater improvement of structural stability, especially the reduction in WEF under NT for the Sceptre C, compared to the other fine-textured soils, may have been due to lower soil organic carbon of the former. Change in GMD was not detectable in the fine-textured soils, thus, changes in WSA, WEF, and GMD in response to tillage operations were greater in the coarse- and medium-textured soils than in the fine-textured soils. This is probably because of the greater role of swelling and shrinking in the clay soils on soil aggregation. Organic molecules are capable of bonding clay particles and cementing larger mineral grains together. Organic matter may contribute to soil structure stability directly as a cementing materials or indirectly through its effect on porosity or water content. Decreasing organic matter contents have been correlated with a loss of stability when a range of stability characteristics are considered such as WSA, dispersibility of clay, tensile strength, and shear strength (Kay, 1990). Therefore, a relative small increase in soil organic matter with NT, either through directly inputs or through reduced decomposition compared with MT or CT, will have a greater impact on the soil structural stability in the light- and medium-textured soils than in the fine-textured soils because of greater amounts of clay and organic matter content associated with the fine-textured soils.

The relationship between WEF and GMD was generally followed a reciprocal function (Fig. 1), either within a soil or pooled over all soils, which supports the findings of Schaller and Stockinger (1953) and Campbell et al. (1993a). In general, WEF rarely exceeded 60% in the medium- and fine-textured soils. However, WEF could exceed more than 60%, or even close to 80% in the coarse-textured soil. Assuming the critical WEF of 60% (Anderson and Wenhardt, 1966), the GMD value calculated based on the reciprocal relationship between WEF and GMD for the Hatton sandy loam soil needed to be 0.32 mm or greater to control severe wind erosion without surface crop residues. To control severe wind erosion in the coarse-textured soils, NT in combination of reducing summer-fallow or completely elimination of summer-fallow was essential in the Brown soil zone. Although it is not clear how the increased crop residues on the soil surface resulting from adaption of NT would affect WSA, WEF, and GMD, these residues will definitely provide additional physical protection against wind and water erosion.

Conclusions

Both tillage system and crop rotation affected WSA, WEF, and GMD in the Brown, Dark Brown and Black Chernozemic soils of Saskatchewan. No-tillage and continuous cropping improved soil structural stability by increasing WSA, and reducing WEF in the coarse- and fine-textured soils, and by increasing WAS and GMD, and reducing WEF in the medium-textured soils. Among the three measured soil physical properties, WSA was the most sensitive parameter to changes in tillage or crop rotations, then WEF, and GMD the least. Elimination of fallow in a crop rotation and adaption of direct seeding proved bo be effective ways in improving soil physical properties, thereby reducing the potential of wind erosion and soil crusting in Saskatchewan.

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Table 1. Soil types, locations, climate, duration of experiments, soil texture, crop rotations and tillage for six tillage and crop rotation experiments conducted in Saskatchewan

Soil	Canadian Taxonomy	Location	Mean annual			Years after initiation	Soil texture		Crop rotation[b]	Tillage system[c]
			Precipitation	Air temperature	Moisture deficit[a]		Sand	Clay		
			---- mm ----	-- ºC --	- mm -	--- yr ---	------ % ------			
Hatton fine sandy loam	Orthic Brown Chernozem	50º24'N 108º00'W	334	3.3	400	11	70.8	15.3	Cont W, F-(W), (F)-W	MT, NT
Swinton loam	Orthic Brown Chernozem	50º16'N 107º44'W	334	3.3	400	12	32.6	27.6	Cont W, F-(W), (F)-W	MT, NT
Sceptre clay	Rego Brown Chernozem	50º36'N 107º48'W	334	3.3	400	11	25.7	42.7	Cont W, F-(W), (F)-W	MT, NT
Elstow clay loam	Orthic Dark Brown Chernozem	52º22'N 108º50'W	355	1.0	270	16	29.0	31.0	W-W-(C)-W-W-X, F-X-W-F-C-W,	CT, NT
Indian Head clay	Rego Black Chernozem	50º32'N 103º40'W	427	2.0	150	8	16.3	63.1	W-W-X-wW, P-S-X-wW, F-W-W-wW	CT, MT, NT
Melfort silt clay	Orthic Black Chernozem	52º51'N 104º37'W	411	0.3	150	25	16.0	44.0	F-(W)	CT, MT, NT

[a] Potential evaporation minus mean annual precipitation (Campbell et al., 1990)
[b] Letters in the parenthesis indicate the rotation phase sampled, W=spring wheat, F=fallow, X=flax, wW=winter wheat, P=pea, C=canola.
[c] CT=cultivator tillage (fall tillage after crop, preseeding tillage, tillage as required for weed control during fallow)
MT=minimum tillage (preseeding tillage, herbicides and tillage used for weed control during fallow)
NT=no tillage (low disturbance direct seeding, all weed control with herbicides)

Table 2. Effects of tillage and crop rotations on water-stable aggregate, wind erodible fraction and geometric mean diameter in the Hatton fine sandy loam

Treatments[a]	Water-stable aggregate	Wind erodible fraction (<0.84 mm)	Geometric mean diameter
	-------------------- %	------------------	------- mm -------
(F)-W - MT	45	70	0.33
(F)-W - NT	49	51	1.25
Cont W - MT	65	63	0.40
Cont W - NT	68	58	0.69
F-(W) - MT	39	71	0.19
F-(W) - NT	58	64	0.43
Contrast within cropping sequences and tillage systems			
F-(W) vs (F)-W	*NS*	*NS*	*NS*
Cont W vs F-W	*P<0.01*	*NS*	*NS*
MT vs NT	*P<0.01*	*P<0.05*	*NS*

[a] F=fallow, W=spring wheat, and letters in the parenthesis indicate the rotation phase sampled, and MT=minimum tillage (preseeding tillage, herbicides and tillage used for weed control during fallow), and NT=no tillage (low disturbance direct seeding, all weed control with herbicides)

Table 3. Effects of tillage and crop rotations on water-stable aggregate, wind erodible fraction and geometric mean diameter in the Swinton loam

Treatments[a]	Water-stable aggregate	Wind erodible fraction (<0.84 mm)	Geometric mean diameter
	------------------- %	-----------------	------- mm -------
(F)-W - MT	27	11	9.4
(F)-W - NT	34	6	63.5
Cont W - MT	51	11	9.1
Cont W - NT	52	4	186.3
F-(W) - MT	31	12	9.2
F-(W) - NT	48	7	86.1
Contrast within cropping sequences and tillage systems			
F-(W) vs (F)-W	*P<0.01*	*NS*	*NS*
Cont W vs F-W	*P<0.01*	*NS*	*P<0.05*
MT vs NT	*P<0.01*	*P<0.01*	*P<0.01*

[a] F=fallow, W=spring wheat, and letters in the parenthesis indicate the rotation phase sampled, and MT=minimum tillage (preseeding tillage, herbicides and tillage used for weed control during fallow), and NT=no tillage (low disturbance direct seeding, all weed control with herbicides)

Table 4. Effects of tillage and crop rotations on water-stable aggregate, wind erodible fraction and geometric mean diameter in the Sceptre clay

Treatments	Water-stable aggregate	Wind erodible fraction (<0.84 mm)	Geometric mean diameter
	-------------------- %	------------------	------- mm -------
(F)-W - MT	50	24	2.48
(F)-W - NT	63	12	19.75
Cont W - MT	64	22	2.74
Cont W - NT	65	13	6.05
F-(W) - MT	60	36	1.74
F-(W) - NT	67	20	3.79
Contrast within cropping sequences and tillage systems			
F-(W) vs (F)-W	*P<0.05*	*P<0.01*	*NS*
Cont W vs F-W	*P<0.05*	*NS*	*NS*
MT vs NT	*P<0.01*	*P<0.01*	*NS*

[a] F=fallow, W=spring wheat, and letters in the parenthesis indicate the rotation phase sampled, and MT=minimum tillage (preseeding tillage, herbicides and tillage used for weed control during fallow), and NT=no tillage (low disturbance direct seeding, all weed control with herbicides)

Table 5. Effects of tillage and crop rotations on water-stable aggregate, wind erodible fraction, and geometric mean diameter in the Elstow clay loam, Indian Head clay and Melfort silt clay

Soil	Tillage or cropping systems[a]	Water-stable aggregate	Wind erodible fraction (<0.84 mm)	Geometric mean diameter
		-------------------- %	--------------------	------ mm ------
Elstow clay loam	CT	72 b	49 a	1.2 b
	NT	84 a	34 b	2.2 a
	FX(W)FCW	70 y	45 z	1.5 y
	FXWF(C)W	73 y	44 z	1.6 y
	WW(C)WWX	91 z	37 y	2.0 z
Indian Head clay	CT	72 b	13 a	11.1 a
	MT	79 a	12 a	7.2 a
	NT	79 a	10 a	9.8 a
	WWX(wW)	78 z	12 z	9.6 z
	PWX(wW)	78 z	12 z	9.3 z
	FWW(wW)	75 y	12 z	9.1 z
Melfort silt clay	CT	74 b	11 a	5.8 a
	MT	77 ab	15 a	3.0 a
	NT	83 a	14 a	5.3 a

[a] F=fallow, X=flax, W=spring wheat, C=canola, wW=winter wheat, P=field pea and letters in the parenthesis indicate the rotation phase sampled, and CT=cultivator tillage (fall tillage after crop, preseeding tillage, tillage as required for weed control during fallow), MT=minimum tillage (preseeding tillage, herbicides and tillage used for weed control during fallow), and NT=no tillage (low disturbance direct seeding, all weed control with herbicides)

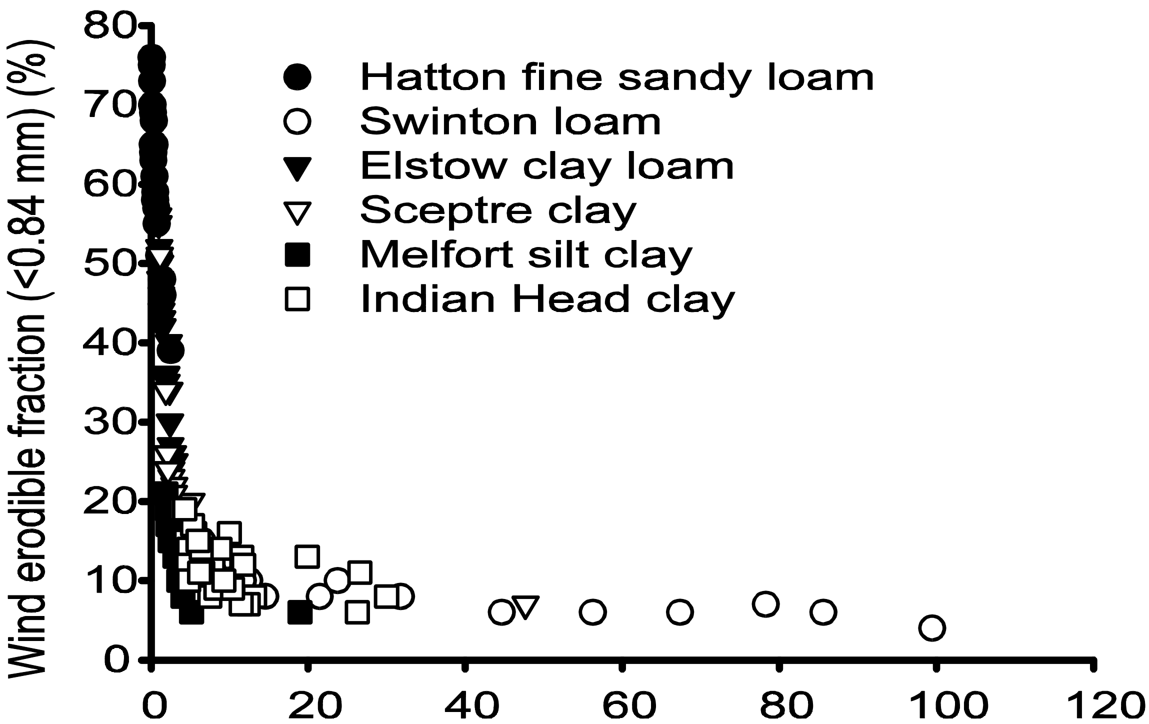

Figure 1. The relationship between wind erodible fraction (<0.84 mm) and geometric mean diameter of soil aggregates in six Chernozemic soils of Saskatchewan