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THE IMPACT OF AGRICULTURE ON SOIL TEXTURE DUE TO WIND EROSION

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ABSTRACT

Wind erosion produces textural changes on topsoil of semiarid and arid environments; however, the selection of particles on different textured soils is unclear. Our objectives were to evaluate textural changes induced by wind erosion on cultivated soils of different granulometry and to asses if textural changes produced by wind erosion are linked to aggregation of granulometric particles into different sizes of aggregates formed in contrasting textured soils. Considering this, we studied the particle size distribution (PSD) with full dispersion (PSD_F) of 14 cultivated (CULT) and uncultivated (UNCULT) paired soils and, on selected sites, the PSD with minimum dispersion (PSD_{MIN}) and the quotient $PSD_{MIN/F}$. Results showed that the content of silt plus clay was lower in CULT than in UNCULT in most of the sites. The highest removal of silt was produced in soils with low sand and high silt content; meanwhile, the highest removal of clay was observed in soils with medium sand content. According to PSD_{MIN}, particles of 250–2,000 µm predominated in the sandy soil, in the loamy soil particles between 50 and 250 µm and in the silty loam soil particles between 2 and 50 µm. For clay sized particles, $PSD_{MIN/F}$ was lower than 1 in all soils and managements, but this quotient was higher in CULT compared with UNCULT only in the loamy soil. This means a decrease of clay accumulation in aggregates of larger sizes produced by agriculture, which indicates an increase in the risk of removal of these particles by wind in loamy soils. Copyright © 2014 John Wiley & Sons, Ltd.

KEY WORDS: irreversible soil degradation process; wind erosion; textural changes; particle size distribution; clay

INTRODUCTION

Wind erosion makes a selection of soil particles, which in the long term, may produce textural changes in the topsoil (Chepil, 1957). This deteriorates the soil, because the blown-out of finer particles decreases the water holding capacity, the organic matter contents and the nutrient status of the eroded soils (Lal, 2001). Because of that, wind erosion is considered a largely irreversible land degradation process, and natural rehabilitation is extremely slow (Holmes *et al*., 2012; Wang *et al*., 2013a). It is therefore sound to measure the changes of the soil texture, in order to asses if they are reliable indicators of soil quality in soils prone to be eroded by wind (Leys, 2006).

Soil texture, mainly silt plus clay (S + C) content, plays a major role in semiarid environments. These particles contribute to the development of soil structure resistant to wind erosion (Buschiazzo *et al*., 1995), decreasing aeolian transport rates (Wang *et al*., 2013b). Soil texture controls the dynamic of organic carbon (OC) accumulation, because fine textured soils have a higher water retention capacity (Saxton & Rawls, 2006), which means higher productivity and therefore higher OC inputs into the soil. Further, higher S + C contents favour higher accumulations of OC because of the formation of organic–mineral complexes (Six *et al*., 2002). The removal of these fine particles also produces negative effects outside the eroded site. Health problems in humans have been reported by the inhalation of particles with diameters less than 10 µm (Norton & Gunner, 1999), transit inconveniences because of low visibility (Hagen & Skidmore, 1977) and, at a global scale, interferences on the interchange of solar and terrestrial radiation, which contribute to the climate change (Alfaro, 2008).

Changes of soil texture by wind erosion have been studied by comparison of paired soils with different erosion degrees (Buschiazzo & Taylor, 1993), by resampling soils after a determined period (Hennessy *et al*., 1986; Lyles & Tatarko, 1986) or, indirectly, by analysing the eroded sediment on single or multiple wind erosion events (Aimar *et al*., 2000). Most of the studies agreed that silts are the particles that are removed in a greater proportion. However, the analysis of loessial soils with different degree of erosion suggested that wind erosion removed a higher proportion of silt and clay in loamy sand soils; meanwhile, on sandy loam soils, silts and fine sands are mostly removed (Buschiazzo & Taylor, 1993). Few studies analyse the selection of fine particles produced by wind on the basis of the original texture of soil surface. Probably differences between soils were due to the aggregation of clay particles, forming coarser aggregates in fine textured soils, but this mechanism is unclear. Therefore, the understanding of particle selection will improve the assessment of soil degradation by wind erosion on soils of different textures.

We hypothesised that clays form coarser and more resistant aggregates in fine textured soils than in coarser textured soils. Therefore, once eroded by wind, finer textured soils will lose a higher proportion of silts and fine sands;

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meanwhile, coarser textured soils will lose a higher proportion of clays and silts. The objectives of this study were (i) to evaluate textural changes induced by wind erosion on cultivated soils of different granulometry and (ii) to asses if textural changes produced by wind erosion are linked to aggregation of granulometric particles into different sizes of aggregates formed in contrasting textured soils.

MATERIALS AND METHODS

This study was carried out in the Semiarid Argentinean Pampas (SAP). The mean annual air temperature of this region is 16 °C and the mean annual rainfall 550 mm. (Casagrande & Vergara, 1996). Soils are developed on Holocene loessial sediments and are classified mainly as Entic Haplustolls (INTA *et al*., 1980).

Fourteen sites on the plain of the SAP were selected on the basis of their textures (Table I). Soil texture of selected soils varied from approximately 100 to 800 g kg^{-1} of silt plus clay because of the variability of texture of the parental material, caused by different sedimentation patterns of loess by winds blowing from SW to NE (Zárate & Tripaldi, 2012). These sites were located in flat positions with slopes lower than 0·5%. At each site, a pair of adjacent fields was sampled. Soil pairs were genetically identical and therefore comparable. The homogeneity of their parent materials was confirmed on the basis of their similar textural composition of C-horizons (data not shown). Management conditions were the following:

i) An uncultivated soil (UNCULT), located in the Caldenal savannalike ecosystem. This is an undisturbed natural grassland environment, submitted occasionally to extensive grazing but remained uneroded by wind or water. UNCULT soils have never been ploughed and represent the original condition of the soils. This ecosystem is composed by a tree strata dominated by Calden (*Prosopis caldenia*, Burkart) and a grass strata dominated by *Stipa tennuis* (Phill) and *Panicum* sp.
ii) A cultivated soil (CULT) ploughed with conventional tillage devices (disc and harrow disc up to 20 cm depth) for more than 50 years, since Calden deforestation. A typical crop rotation carried out on these soils is wheat – cattle grazed oat – summer crops. Historical information indicates that the land use has been rather uniform in the entire region (Viglizzo *et al*., 1997). However, in recent years, the proportion of summer crops has been increased. Of these, soybean (*Glycine max*) is the crop most cultivated in the last seasons (SIIA, 2013).

Triplicate random samples of the top soil (20 cm) were taken from three 10-m^2 sampling areas between August and September of 2005 in each site. Samples were air dried and passed through a 2-mm sieve. In these samples, we determined the particle size distribution (PSD) using the combined wet sieving and pipette method described by Gee & Bauder (1986). First, we determined PSD after chemical and ultrasound dispersion pretreatments. This treatment was designed full dispersion (PSD_F).

Three sites with different textural classes on UNCULT soils were selected as a function of PSD_F in order to represent coarse, medium and fine textured soils of the SAP: sites 1 (sandy), 8 (loamy) and 11 (silty loam). PSD with a minimum dispersion pretreatment (PSD_{MIN}) was determined on these samples. For this purpose, 20 g of 2-mm sieved soil was weighted and shaken inside a 250-mL glass bottle with 200-mL of distilled water for 2 h at 180 rpm in a reciprocal shaker. Finally, it was transferred to a 1-L sedimentation cylinder for the determination of grain size analysis by means of wet sieving and the pipette method.

The PSD_F was separated according to the classes established by USDA (Soil Survey Division Staff, 1993). Very fine sands (VFS) were divided into two classes according to particle diameter (Ø): VFS I (50 µm < Ø < 73 µm) and

Table I. Mean values of clay, silt, organic carbon (OC) and texture class of each uncultivated soil ($n = 3$)

Site	Clay		Silt		OC		Texture class
	g kg^{-1}						
1	57	(3)	70	(3)	5	(1)	Sand
2	105	(22)	121	(32)	18	(4)	Sandy loam
3	76	(3)	196	(9)	12	(4)	Sandy loam
4	104	(13)	177	(14)	14	(2)	Sandy loam
5	138	(15)	306	(16)	36	(10)	Sandy loam
6	136	(12)	316	(13)	55	(12)	Sandy loam
7	158	(16)	295	(9)	50	(1)	Sandy loam
8	204	(14)	396	(15)	49	(17)	Loam
9	209	(32)	442	(36)	41	(8)	Loam
10	233	(14)	428	(55)	48	(6)	Loam
11	192	(7)	500	(40)	20	(2)	Silt loam
12	243	(61)	487	(60)	25	(17)	Loam
13	228	(21)	535	(23)	68	(17)	Silt loam
14	276	(72)	563	(37)	85	(47)	Silty clay loam

Standard deviations are in parentheses.

VFS II (73 μm < Ø < 100 μm). We also calculated silt plus clay as the sum of 50 μm < particles (Six *et al*., 2002). The mean effects of the treatments on these classes were analysed by a two-way analysis of variance with site and management as main factors to test interaction effects. When we found interaction effects, managements were compared within the site using a Student's *t*-test. To analyse the change of the studied classes, we used the quotient between the proportion of each fraction in CULT (X_C) and in UNCULT (X_{UC}) (Equation 1).

$$X_{C/UC} = \frac{X_C}{X_{UC}} \quad (1)$$

To study the change that management produced on each grain size fraction in relation to the uncultivated soil, the index of Equation 1 was correlated with the total sand content of the corresponding paired UNCULT soil by linear and nonlinear models using the CurveExpert 1·3 software (Hyams, 2005).

The following PSD_{MIN} fractions were determined: Ø < 2 μm, 2 μm < Ø < 50 μm, 50 μm < Ø < 250 μm, and Ø > 250 μm. The effect of management on each fraction was compared within the site by means of the Student's *t*-test.

To estimate the proportion of particles forming aggregates, we used the quotient between PSD_{MIN} and PSD_F ($PSD_{MIN/F}$) for each textural size fraction. In the case of clay sized particles, this quotient took values between 0 and 1. The smaller this value is, the greater the amount of clay that is forming coarser aggregates. For the 2–50 μm and 50–250 μm sized particles, this quotient represents a dynamic balance, as it reflects the gain of aggregates of smaller particles and simultaneously the outflow of particles of these sizes (X) that form larger sizes aggregates. The quotient took values less than 1 when the input of particles smaller than these sizes ($x < X$) was lower than the input of particles X to fractions of larger sizes ($X<$) and greater than 1 if the behaviour is opposite. Finally, for particles >250 μm, this quotient took values higher or equal to 1. The greater this value is, the greater the amount of smaller particles that is forming aggregates of these sizes.

The effect of management on each fraction was compared within the site by Student's *t*-test. All tests were performed at a 0·05 probability level using the INFOSTAT software (Di Rienzo *et al*., 2002; FCA-UNC, Córdoba, Argentina).

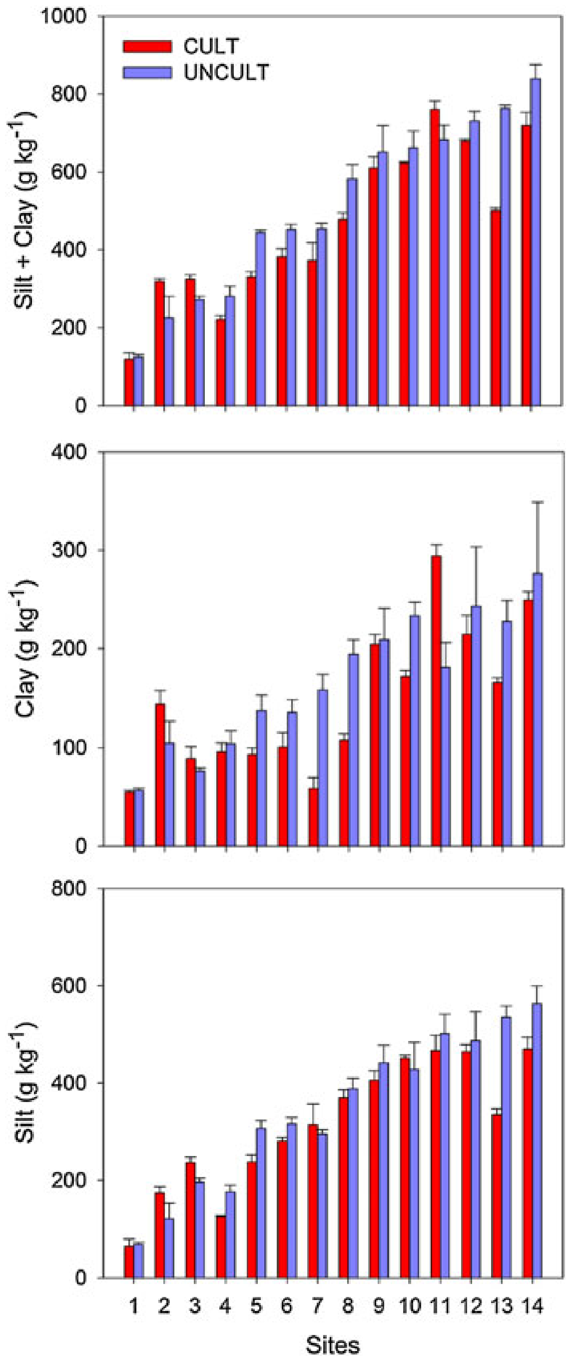

Figure 1. Primary particle size contents of silt plus clay, clay and silt in cultivated (CULT) and uncultivated (UNCULT) soils, in the upper 20 cm of soil in the studied sites, after the full dispersion treatment of soil samples. Vertical bars indicate standard deviation ($n = 3$). This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

RESULTS AND DISCUSSION

Particle Size Distribution of Full-Dispersed Samples

The analysis of variance showed a *site x management* interaction for S + C ($p < 0{\cdot}001$), so we compared this fraction between managements inside each site. The S + C contents varied between 100 and 785 g kg^{-1} in CULT, with an average of 460 g kg^{-1}, and between 124 and 881 g kg^{-1} in UNCULT, with an average of 514 g kg^{-1}. According to Figure 1, the S + C contents were lower in CULT than in UNCULT in sites 4 to 8 and 12 to 14, and higher in sites 3 and 11 ($p < 0{\cdot}05$). These results agree with those of Lyles & Tatarko (1986), who found a decrease of S + C contents in cultivated soils of Kansas eroded by wind for more than 30 years.

There was a *site x management* interaction for clay contents ($p < 0{\cdot}001$). Figure 1 shows that clay contents ranged between 50 and 307 g kg^{-1}, with a mean of 146 g kg^{-1} in CULT, and between 54 and 360 g kg^{-1}, with a mean of 169 g kg^{-1} in UNCULT. Clay contents were higher in UNCULT than in CULT in sites 5 to 8 and 13 and lower in site 11 ($p < 0{\cdot}05$). Buschiazzo & Taylor (1993) reported losses of clay by wind erosion in a loamy sand soil and gains in a sandy loam of the SAP. In soils of coarser textures (sites 1 to 4), clay contents were similar between managements. These results coincide with those of Hennessy *et al.* (1986), who found similar contents of clay between eroded and non-eroded sandy soils of New Mexico. In medium textured soils (sites 5 to 8 and 10), this decrease represented a removal of 32% to 68% of clay contents from CULT. These losses can be attributed only to an increment of wind erosion rates in cultivated soils, because the studied sites were on flat positions with no evidence of water erosion.

There was an interaction *site x management* for silt contents ($p < 0{\cdot}01$). Figure 1 shows that silt contents varied between 48 and 502 g kg^{-1}, with a mean of 314 g kg^{-1} in CULT, and between 67 and 588 g kg^{-1}, with a mean of 345 g kg^{-1}, in UNCULT. The content of silt was lower in CULT than in UNCULT in sites 4 to 6, 13 and 14 and higher in site 3 ($p < 0{\cdot}05$). The removal of silt represented 5% to 37% of the original silt contents. Zobeck *et al.* (1995) compared a cultivated and an adjacent natural pasture soil on Texas and found higher contents of silt in the natural soil. These authors attributed these higher contents to the sedimentation of silt during past wind erosion events.

There was no interaction *site x management* for very fine sand I (VFS I, 50–73 μm). The mean content of VFS I in CULT was 119 g kg^{-1} and 111 g kg^{-1} in UNCULT ($p < 0{\cdot}05$). On the other hand, there was a very strong interaction *site x management* for very fine sand II (VFS II, 73–100 μm), fine sand (FS, 100–250 μm) and sands >250 μm contents ($p < 0{\cdot}001$). Contents of VFS II were higher in CULT than in UNCULT ($p < 0{\cdot}05$) in sites 6 to 8, 13 and 14 (Figure 2). Contents of FS were higher in CULT in sites 3 to 11, 13 and 14; meanwhile, they were lower in sites 3 and 11 (Figure 2). Contents of >250 μm sands were higher in CULT in sites 13 and 14 but lower in sites 2 and 3 (Figure 2). These results agree partially with those of Buschiazzo & Taylor (1993), who reported a higher content of VFS I in an eroded sandy loam soil. These authors also found a higher content of FS in an eroded soil but only when the total sand content was lower than 60%. Blank & Fosberg (1989) compared six cultivated and uncultivated paired soils and found higher content of VFS in cultivated soils. These results could be attributed to the accumulation of these particles, even in cultivated soils, from spots inside the field with higher erosion rates, as wind erosion produces an internal redistribution of sands inside the field as the mechanism of transport of these particles are short term suspension and saltation (Goossens & Gross, 2002; Shao, 2008).

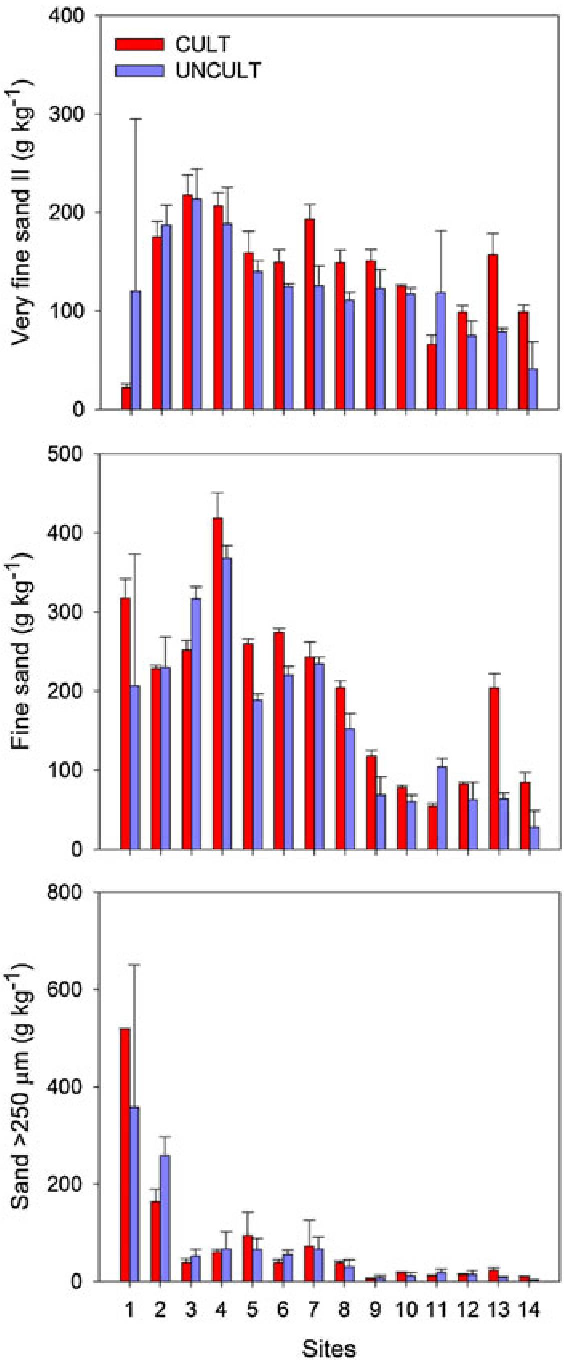

Figure 2. Primary particle size contents of very fine sand II (73–100 μm), fine sand and sand >250 μm in cultivated (CULT) and uncultivated (UNCULT) soils, in the upper 20 cm of soil in the studied sites, after the full dispersion treatment of soil samples. Vertical bars indicate standard deviation ($n = 3$). This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

Particle Size Distribution Changes Due to Management

Figure 3 shows the variation of the index $S + C_{C/UC}$ as a function of sand contents of UNCULT. This index varied between 0·6 and 1·4, being most of the values less than 1. Although the relationship between $S + C_{C/UC}$ and $sand_{UC}$ was not statistically significant, a quadratic trend was detected with minimum $S + C_{C/UC}$ values between 200 and 400 g kg^{-1} of $sand_{UC}$, decreasing progressively between 400 and 600 g kg^{-1} and reaching 1 at approximately 750 g kg^{-1} of $sand_{UC}$. This can be explained by the combination of aggregate breakdown by tillage (Hevia *et al.*, 2007) and the higher losses of particles by suspension on sandy loam – loamy sand soils compared with coarser and finer textured soils (Goossens & Gross, 2002).

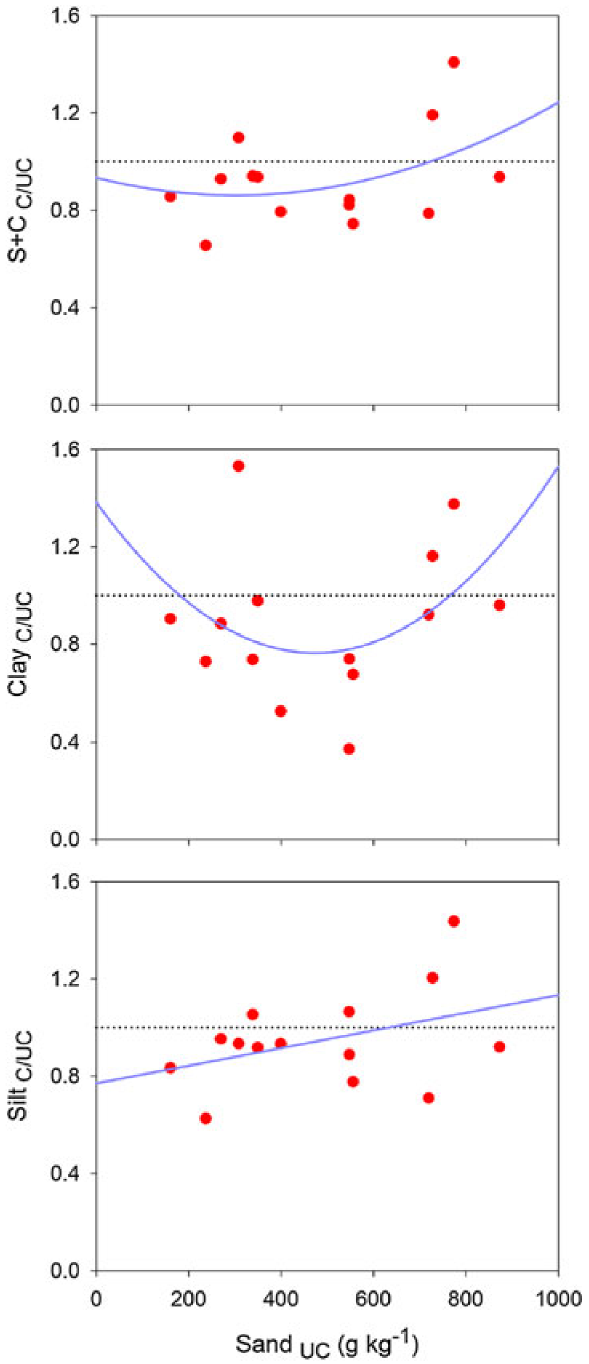

Figure 3. Variation of the quotient between the sum of silt and clay ($S + C_{C/UC}$), clay ($Clay_{C/UC}$) and silt ($Silt_{C/UC}$) of cultivated and uncultivated soils in relation to total sand contents of the uncultivated soil ($Sand_{UC}$), obtained from full-dispersed soil samples. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

Figure 3 shows that soils with medium sand contents ($400–600\,g\,kg^{-1}$) presented the highest differences of clay contents between CULT and UNCULT soils. Buschiazzo *et al*. (2000), comparing paired soils with different erosion degrees, found that changes of clays contents as a function of sand followed a positive linear tendency, proposing a threshold value of 40% of sand. Below this value, eroded finer soils increased their clay proportion and coarser soils decreased. In our case, this trend was quadratic. The difference with results of Buschiazzo *et al*. (2000) can be attributed to the increase of wind erodible aggregates by breakdown of tillage in medium textured soils (Colazo & Buschiazzo, 2010) and to a higher aggregation of clays in finer soils, which decreased their susceptibility to be eroded by wind (Chepil, 1957). When sand contents increased, the proportion of these aggregates decreased or become less stable. Hagen (2004) affirmed that when the relationship between sand coarser than 100 µm (sand that moves by saltation) and clay is high, the amount of clay available in the aggregates to be removed by sandblasting is low; meanwhile, when the relationship is low, the forces of cohesion reduces the sandblasting process, hence the maximum rates of rupture of aggregates occur on values of >100 µm sands: clay ratio of 0·1 to 10, which coincide with the equivalent of total sand where higher losses occurred in our study.

The higher removal of silt occurred in soils with low sand and high silt contents (Figure 3). Aimar *et al*. (2012) found that losses of particles smaller than 10 µm (mainly fine silts) were positively related to silt contents of the soil and negatively to organic matter contents. They attributed these trends to the low stability and high susceptibility to be transported by wind of silt sized aggregates (Chepil, 1957).

Figure 4 shows the variation of the $X_{C/UC}$ ratio of the different fractions of sand analysed as a function of the total contents of sand in UNCULT. An exponential model best fitted the relationships in all the fractions. This would indicate that the increase of sand is higher in fine textured soils. This probably reflects a higher removal of particles <50 µm. The better fitting for fractions higher than 100 µm can be explained by their modes of transport, saltation and creep, which further reflect accumulation processes (Goossens & Gross, 2002).

Particle Size Distribution with Minimum Versus Particle Size Distribution with Full Dispersion

Figure 5 shows the grain size distribution of minimum dispersed soils (PSD_{MIN}). Both the sandy CULT and UNCULT soils (site 1) presented grain size distributions dominated by 250–2,000 µm particles, which represented more than 50% of all fractions. This fraction increased while the 50–250 µm decreased in CULT soils as compared with UNCULT ones ($p < 0{\cdot}05$). In the loamy soil (site 8), particles between 50 and 250 µm were dominant. In CULT, the proportion of particles <2 µm was higher and the 250–2,000 µm was lower than in UNCULT ($p < 0{\cdot}05$). This change was not generated by an increase of primary clay particles (Figure 1). In the silty-loam soil (site 11), particles between 2 and 50 µm predominated. The proportion of particles <50 µm was higher in CULT than in UNCULT, the proportion of 50–250 µm particles was lower ($p < 0{\cdot}05$) and the proportion of 250–2,000 µm was similar. It is suggested that disintegration of macroaggregates into microaggregates by tillage is the first step of loss of soil structure (Amezketa, 1999). These results indicated an increase in the potential emission of particles <2 µm in the loamy soil and particles <50 µm in the silty-loam soil, as a consequence of tillage operations.

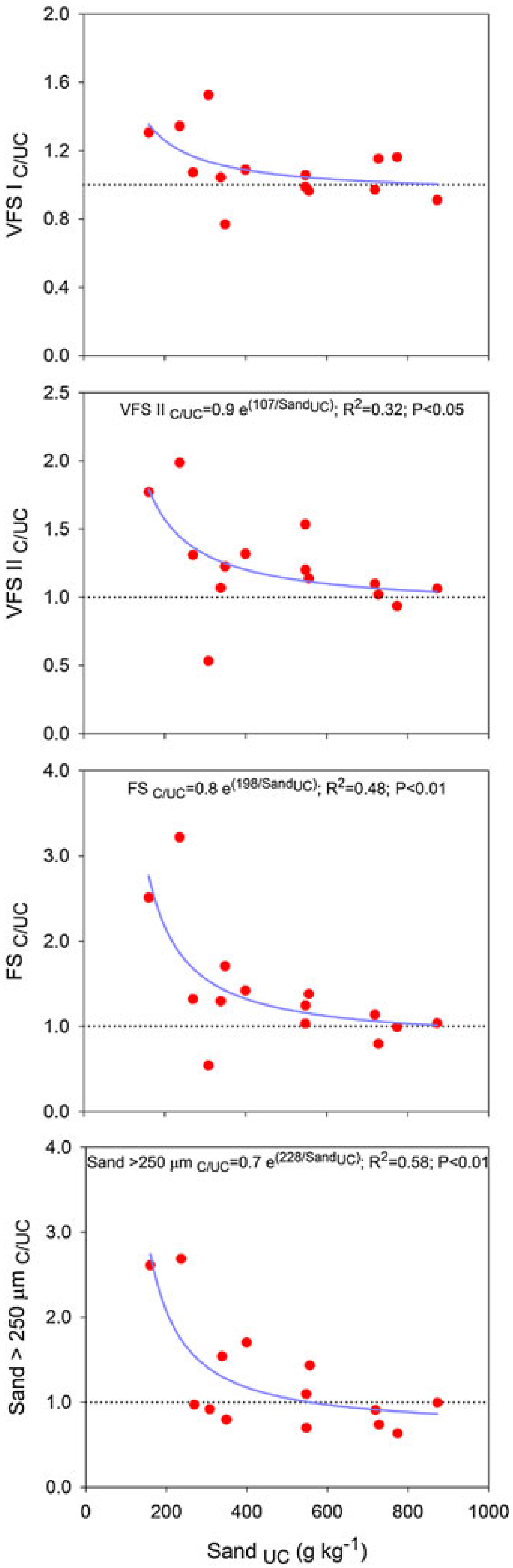

Figure 4. Variation of the quotient of particles contents of cultivated and uncultivated soils in relation of total sand content in the uncultivated soil ($Sand_{UC}$), obtained from full-dispersed soil samples, to very fine sand I (VFS $I_{C/UC}$, 50–73 µm), very fine sand II (VFS $II_{C/UC}$, 73–100 µm), fine sand ($FS_{C/UC}$, 100–250 µm) and sand coarser than 250 µm (Sand > 250 $\mu m_{C/UC}$). This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

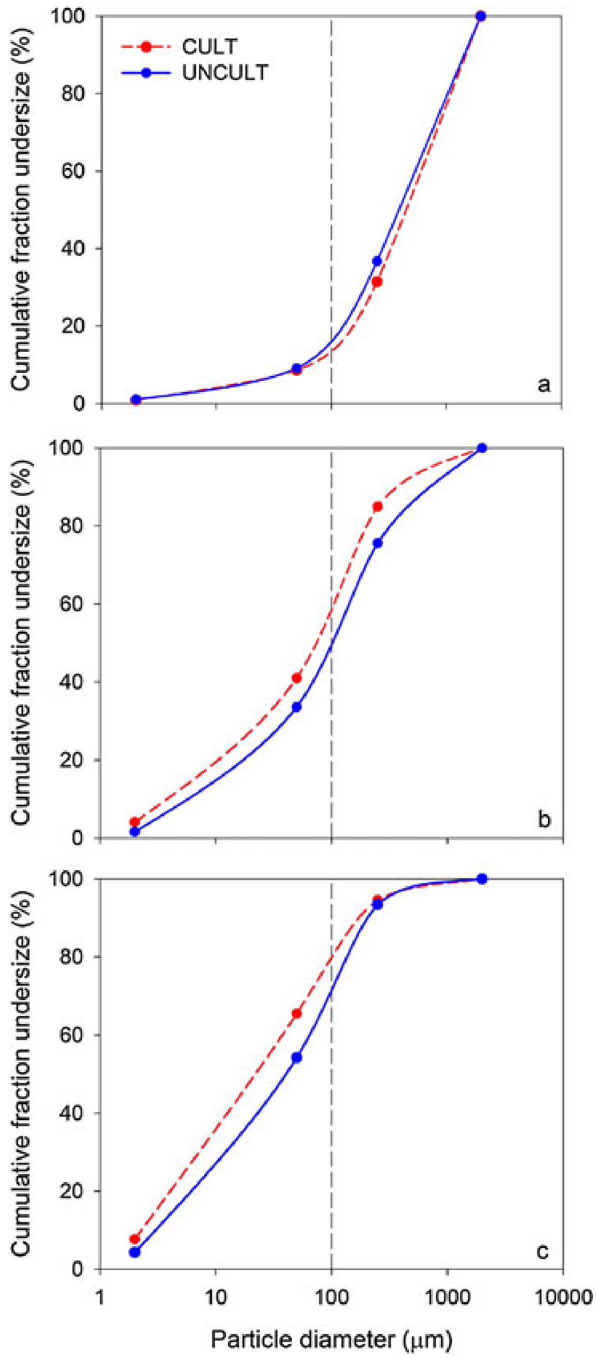

Figure 5. Cumulative fraction undersize curve of minimum dispersed particles of a paired soil with different management: cultivated (CULT) and uncultivated (UNCULT) on (a) sandy, (b) loamy and (c) silty-loam soil. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

Table II shows the quotient between PSD of soils obtained with minimum and full dispersion ($PSD_{MIN/F}$). For clay sized particles (<2 µm), the values of this quotient were less than 1 in all soils and managements. This means that part of the clay is forming particles of higher sizes (Martínez Mena *et al*., 2000). In sandy soils, clay can be attached to sand grains and in finer textured soils forming aggregates (Shao, 2008). $PSD_{MIN/F}$ was higher in CULT compared with UNCULT only in the loamy soil. This means a decrease of clay accumulation in aggregates of higher sizes produced

Table II. Quotient between particle size distribution of minimum and full-dispersed samples ($PSD_{MIN/F}$), in cultivated (CULT) and uncultivated (UNCULT) soils, in three sites

Site	Size classes (μm)	$PSD_{MIN/F}$				p
		CULT		UNCULT		
1	<2	0·17	(0·01)	0·18	(0·02)	0·15
	2–50	1·22	(0·21)	1·15	(0·11)	0·63
	50–250	0·63	(0·05)	0·79	(0·12)	0·09
	250–2,000	1·33	(0·04)	1·22	(0·09)	0·12
8	<2	0·38	(0·09)	0·08	(0·02)	0·01
	2–50	1·00	(0·13)	0·81	(0·05)	0·07
	50–250	0·91	(0·07)	1·12	(0·08)	0·03
	250–2,000	3·98	(0·43)	11·04	(1·73)	0·01
11	<2	0·26	(0·02)	0·22	(0·05)	0·29
	2–50	1·24	(0·13)	1·00	(0·09)	0·06
	50–250	1·30	(0·25)	1·34	(0·18)	0·83
	250–2,000	4·65	(0·34)	5·48	(1·19)	0·30

p = probability level of the *t*-test carried out between management systems.
Standard deviations are in parenthesis, $n = 3$.

by management, which indicates an increase in the risk of removal of these particles by wind. Probably, this can be associated with the decrease of OC produced by tillage in these soils (Buschiazzo *et al*., 1991; Colazo & Buschiazzo, 2010). It has been shown that tillage reduces OC, mainly in macroaggregates (Barbera *et al*., 2012), increasing the proportion of water-dispersed clay (Dexter *et al*., 2008). Also, in soils with medium contents of clay and sand, the mechanism of disaggregation of clay can be mainly linked to sandblasting produced during wind erosion events (Shao *et al*., 1993), which is the main mechanism producing the emission of particles <2 μm, mainly in medium textured soils (Gillette & Walker, 1977).

The $PSD_{MIN/F}$ quotient for particles between 2 and 50 μm was greater than or equal to 1 in all soils and managements, indicating that the participation of clays on the formation of silt sized aggregates was greater than for the formation of silt and sand sized aggregates. This means that a better aggregation capacity of clay occurred in most cases, with exception of UNCULT in the loamy soil. Probably, in this soil, clays and silts formed aggregates coarser than 50 μm. $PSD_{MIN/F}$ was similar between managements; however, this quotient increased as a function of cultivation in the loamy and particularly in the silty-loam soils ($p \approx 0{\cdot}05$).

For particles between 50 and 250 μm, $PSD_{MIN/F}$ was lower than 1 in the sandy soil, higher than 1 in the silty loam soil, and decreased by management in the loamy soil ($p < 0{\cdot}05$). This indicates that in the sandy soil the contribution of VFS and FS to the formation of >250 μm sized aggregates was greater than for the formation of 50–250 μm aggregates. This was probably due to the low content of clay and silt in this soil. In the loamy soil, the breakdown of these aggregates by tillage and the increase of sandblasting during wind erosion events could be responsible for this decrease. In the silty-loam soil, a ratio greater than 1 indicates that the contribution of clay and silt to the formation of 50–250 μm aggregates was higher than that of VFS and FS to the formation of coarser aggregates.

In sandy soils (more than 60% sand), the proportion of clay was similar between cultivated and uncultivated conditions. In the sandiest soil (site 1, >80% of sand), contents of <50 μm particles were similar between CULT and UNCULT. The particles larger than 250 μm predominated in sandy soils. These particles are transported mainly by saltation or creep, so they move restricted distance, and therefore, they accumulate inside or near the eroded field. The particles <100 μm, which can potentially be transported by suspension, represented less than 20% of the total particles, so probably despite high windblown activity, the loss of these particles by dust will be minimal (Wang & Jia, 2011). In this soil, the management did not change the $PSD_{MIN/F}$ of clay sizes, indicating that management did not modify its accumulation within the large and more wind erosion resistant aggregates.

In general, soils with sand contents ranging from 20% to 60% showed the highest removal of particles <50 μm, and soils with 40% to 60% of sand lost mostly clays. In these medium textured soils, the amount of <100 μm particles was approximately 60% in CULT and 50% in UNCULT. In UNCULT, most of the clays formed larger aggregates, probably those >250 μm, as $PSD_{MIN/F}$ of this size class is greater than 1. $PSD_{MIN/F}$ of clay was higher in UNCULT than in CULT, indicating a disaggregating process, probably by a combination of the breakdown produced by tillage operations, the sandblasting during wind erosion events and the lower aggregation produced by the lower OC contents. This indicates an increase of the risk of losing these particles by suspension.

The cultivated soils of fine textures (sand <40%) only showed reductions of clay contents in two sites and increases in one site. In these soils, the differences between management of the contents of particles smaller than 50 μm were mainly due to a decrease of silt and to a lesser extent of clay. The accumulation of clay in coarser aggregates was not modified by management. In silt loam soils

(≈60% silt), particles (primary particles and aggregates) smaller than 100 µm represented about 80% in CULT and 70% in UNCULT. This indicates a high susceptibility of these soils to lose these particles by emission, which probably explains the high losses of primary particles of silt size.

Textural changes produced by erosion mentioned earlier surely had effects on the soil water holding capacity of the top soil. Using the pedotransfer function developed by Saxton & Rawls (2006), this change is equivalent to a mean decrease of 2 mm of the estimated available water and up to 10 mm in the most eroded soil. Assuming the theoretical model of OC accumulation on reference soils of the studied region developed by Buschiazzo *et al*. (1991): OC $[\%] = a + 0{\cdot}057\,S + C\ [\%]$, the removal of silt and clay implicated a mean decrease of the soil OC sequestration capacity of 2·3 and of $15\,g\,kg^{-1}$ in the most eroded soil. However, these losses are more important in medium textured soils, which lost mainly clays by wind erosion, which also will increase the susceptibility of the soils to be further eroded by wind due to an increase of the erodible fraction and a decrease of the dry aggregate stability (Colazo & Buschiazzo, 2010).

CONCLUSIONS

Wind erosion selectively removed fine particles in CULT soils in relation to UNCULT soils. Finer and medium textured cultivated soils (sand <60%) showed a removal of clay and silt. Soils of low sand and high silt contents lost a higher proportion of silt, while soil of medium sand content (40–60%) had a higher proportion of clay. In general, sand fractions increased in CULT soils indicating accumulation processes. This pattern of removal by wind erosion among soils can be attributed to differences on their minimum dispersed particles distribution and to the reduction of clay proportion in aggregates more resistant to wind erosion. This indicates that loessial medium textured soils reduce their quality more than extreme textured soils as a consequence of wind erosion in combination with tillage. Tillage and wind erosion breakdown aggregates and wind removes fine particles, mainly clay, increasing the soil susceptibility to be further degraded.

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