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Soil condition threats in two seasons of extreme weather conditions

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ABSTRACT

This research started from the observation that soil state defects that occur in a season may result in even more serious after-effects in the following year. The objective of this study was to investigate the striking forms of deterioration in a Chernozem soil that occurred both in the surface and in the deeper layer. In one respect, dust formation, crumb reduction, surface silting, and surface crusting were studied, and an attempt to investigate additional consequences of the dust sedimentation to the nearest compacted layer was made. The degree of the soil deterioration was compared under treatments of bare and covered surfaces and in degraded and preserved soil conditions setting in the selected parts of a long-term trial. Surface cover significantly influenced soil vulnerability resulting in different responses of soil attributes. The surface crust reducing effects of a higher (≥ 55%) surface cover ratio and a lower proportion of dust could statistically be proven ($P < 0.001$). A favourable rate of surface cover reliably reduced the ratio of clods produced by primary tillage in dry (0.138–0.158 g/g) soil. The results indicate that it is possible to complete methods adaptable to the climate threats mitigation.

Keywords: soil quality; erosion; damage; degradation; rainfall

The climate was rather extreme during the past decade in the Carpathian basin (Szalai and Lakatos 2013). Increasing attention has been paid to climate induced damage in literature, a number of publications focusing on soil erosion by water or wind (e.g. Bašić et al. 2004, Übelhor et al. 2014). Both excess and shortage of water make tillage more difficult and for this reason, they contribute to the soil quality deterioration. The impacts of tillage improving or degrading the soil were properly discussed (e.g. Cook et al. 2006, Guo and Wang 2013). Likewise, Birkás et al. (2012) and Bottlik et al. (2014) observed and published rain-induced phenomena e.g. surface silting, dust sedimentation to the nearest compacted layer, soil settling due to the repeated rainfall. Authors ranked values of the measured parameters, although passed over the detailed evaluation of the assessed damages.

Some of the soil condition defects are visible, e.g. the disintegration of crumbs, surface silting and crusting, however it does not help prevention since consequences are not being considered to be as serious as they actually are (Várallyay 2014). Surface crusting is considered as an important factor during sowing and emergence (Gallardo-Carrera et al. 2007), but hardly any attention is paid to the same during the rest of the growing season, in spite of the fact that it is always an important soil quality indicator (Badorreck et al. 2013). It can be assumed that some of the climate-related phenomena that afflicted the soil in the rainy season may induce cumulative damages in soil, therefore certain forms may appear more exponentially in a subsequent dry season. This is why we focused our research on studying changes taking place in the soil that are less widely rec-

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ognised, in two extreme seasons, in one of which the annual precipitation exceeded the long-term average by 371 mm (2010) and in the other it fell 283 mm short of the long-term average (2011).

Climate- and tillage-induced soil defects were investigated in soils of bare and covered surfaces and in degraded and preserved state to establish the degree of the soils' physical deterioration in rainy and dry periods, presenting changes in crumb ratios, surface silting, surface crusting, and thickening surface crust and tillage pan.

MATERIAL AND METHODS

The site and the design of the experiment. The problem was studied in the selected parts of the long-term soil quality-climate experiment plots, from 2002 at the Experimental and Training Farm of the Szent István University, located in the region of the town, Hatvan (47°68'N, 19°60'E, 130 m a.s.l), 60 km north-east of Budapest. The terrain of the research site is flat, with soil of a clay-loam texture (Calcic Chernozem, WRB 2006), a humus content of 2.96% (2011) and moderate sensitiveness to compaction; the sand, silt and clay contents of the top 20 cm layer are 23, 42 and 35%, respectively (Csorba et al. 2011). This soil is categorised as dry, humid or wet when its moisture content ranges between, 0.148–0.189, 0.190–0.239, or > 0.240 g/g, respectively (Csorba et al. 2011). Moisture content of the soil concerned plays an important role in the vulnerability. Some of the phenomena e.g. dust leaching, compacted layer extension, surface silting may ensue following abundant rains at high soil moisture content. Other phenomena assessing in dry circumstances (crumb reduction, dust and clod formation, crusting) have already begun to develop previously e.g. under rainy period.

The original experiment was set up on 13 m × 180 m plots in four replicates in a split-plot design (Sváb 1981). Total area of the trial including edges covers 6.2 hectares. Six tillage treatments are applied comprising deep (≥ 0.30 m, that is loosening, ploughing, and tine tillage) and shallow (≤ 0.20 m, that is tine tillage and disking) soil disturbance and no-till. Studying climate impacts on soil, five micro plots were pointed in each experimental plot with an area of 4 m × 4 m. A relatively high (20) number of micro plots were used considering the required soil disturbance of some types of sampling. Two surface condition treatments were selected for investigation: bare surface (BS) and covered surface (CS, 55%), and two soil quality levels, that is degraded (BSD, CSD) and preserved (BSP, CSP). Soil state has differently developed by long-term effect of the various tillage treatments. Thus, the BSD treatment was positioned in ploughed, and the CSD in the loosened soil. In addition, the BSP and the CSP treatments were placed in the tine tilled soils.

Surface cover by crop residues. Crop sequence has actually been subordinated to the soil quality preservation for decade. In 2009 (that is in preceding year of the investigation), winter wheat (*Triticum aestivum* L.), in 2010 maize (*Zea mays* L.), and in 2011 spring oat (*Avena sativa* L.) were sown in the experiment. Chopped residues of these crops were applied to the CS, and to the further surface cover treatments. At least soil surface was sufficiently covered by crop residues after planting. A total of 14 different soil cover ratios were created, ranging from 1–65% (1, 5, 10...60, 65%) to study the impacts of soil surface cover. The chopped straw cover ratios were checked using 50 cm × 50 cm quadrate device and the meterstick method (Hartwig and Laflen 1978), and finally, adjusted to the planned ratio.

Sampling for soil condition tests. Soil state measurement was realised during the growing season (1 April–30 September) in both years. Samples to check soil condition and moisture content were taken usually in 20-day intervals in each treatment in five repetitions. Intervals were postponed at the muddy circumstances for obvious reasons.

Crumbs in the national soil physics categorisation system are defined as soil aggregates ranging from 0.25–10 mm in diameter, of which those falling in the range of 0.25–2.5 mm qualify as small crumbs. In this system the < 0.25 mm soil particles are classified to be dust (Dvoracsek 1957, Filep 1999). The crumb (0.25–10 mm) ratio, measured at optimal moisture content (0.190–0.239 g/g) made up 57.3% at preserved and 41.4% at degraded soil treatment. Regular sampling of the soil agronomic structure during the rainy season revealed a continuous decrease of the dust ratio in the tilled layer.

The soil samples separating the various particles were air-dried and then they were gently sieved (60 shakes/min). The mass distribution between the grades was also established.

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Separation of the soil particles including clods (> 30 mm) produced by primary tillage after the growing season was performed from 50 cm × 50 cm sampling places to the depth of the soil disturbance.

The ratios of silting (in 2010) and crusting (in 2011) area were assessed with a quadrate (50 × 50 cm) device in the half area of the selected plots also in the specified time intervals. The thickness of the crusts and extensions of pan layer were measured on a soil cube (edge of 40 cm) extracted from the concerned areas.

Occurrence, depth and extension of compaction in soils can properly be measured by penetrometer instruments. However, the real degree of compaction can only be stated with full knowledge of the soil moisture content (Dexter 1988). For that reason parallel measurements were used in this experiment. Methods and instruments of soil moisture and penetration resistance measurements were described in details in the paper that was already published (Kalmár et al. 2013a). No harmful compaction (> 3.0 MPa at soil moisture range of 0.190–0.229 g/g) developed in the soils until November 2009. The original ≤ 5 mm tillage pan grew thicker in the rainy season and its presence was observed in 14 thickness categories between 5–74 mm below the depth of the loosened layer at the BS soil treatment. In addition, the occurrence and the thickness of the compacted layer were assessed visually three times in the growing seasons with the aid of the spade probes.

Meteorological conditions. The precipitation was measured at the weather station of the training farm. The multi-year average of the precipitation (580 mm) and the monthly distribution seems favourable in the micro region (Figure 1). However, the last decade including years of investigation was characterised by extreme annual and monthly variability. The year 2010 is considered to be rainy in the regional rating, with regard to the total amount (962 mm) of precipitation, while year 2011 proved to be dry with respect to the low amount (297 mm) of precipitation. Soils probably suffered from the various weather incidences during the preceding years of the investigation, although in slight extent.

Statistical analyses. Averages and correlations between the individual characteristics were calculated using the Microsoft Excel HU software (Szent István University, Gödöllő, Hungary, 2010). ANOVA was performed at a 0.05 level of significance to determine whether the treatments were different. Multiple comparisons were made between the significant effects using the least significant difference (*LSD*) test at α = 0.05. Treatment main effects on soil attributes were tested using bi-variant regression analysis (Sváb 1981). To analyse the parallel effect of the surface cover and the dust ratio in the surface layer on crust formation a regression analysis with two independent variables (Sváb 1981) was used.

RESULTS AND DISCUSSION

Soil surface degradation in rainy and in dry periods. Negative changes were found in the surface

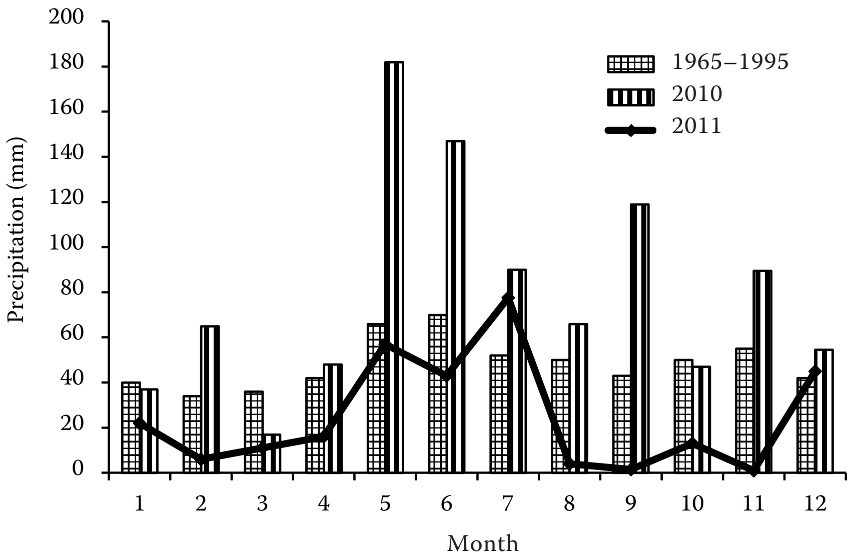

Figure 1. Monthly precipitation in the years of investigation (2010, 2011) and in the 30-year period on the Experimental and Training Farm of the Szent István University, Hatvan, Hungary

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layer at lower (< 0.19 g/g), and at higher moisture content (> 0.24 g/g) (Table 1). Three types of the soil deterioration could be stated that are highly (BSD), moderately (CSD, BSP) and slightly (CSP) vulnerable to the climate impacts. Surface cover was proved to be effectual at both soil quality (SD, SP) categories. In degraded and bare soils (BSD) half of the crumbs were damaged, but only a quarter of them were deteriorated at the covered (CSD) treatment. The difference between various soil quality and the presence or absence of surface cover could be proven statistically ($P < 0.001$). During rainy periods crumbs that had already been damaged were transformed into a film of silt of which formed a hard crust when the rains were followed by dry period. This phenomenon grew particularly harmful at the BSD treatmant (Table 1). Similar phenomena have already been observed by other authors as well (Gallardo-Carrera et al. 2007, Mulkholm et al. 2013). As Dexter (1988) and Csajbók et al. (2014) emphasised, tillage alone cannot remedy a soil that has suffered severe degradation.

Table 1. The means and standard error (SD) of four types of soil surface deterioration in the evaluated plots

	Soil	Bare	Covered
Crumb reduction (%)	D	48.0[a]	26.0[c]
	P	28.0[b]	7.0[d]
	mean	38.0	16.5
	$LSD_{0.05}$	1.522	4.461
Surface silting (%)	D	74.0[a]	43.2[c]
	P	49.2[b]	6.0[d]
	mean	61.6	24.6
	$LSD_{0.05}$	1.852	4.537
Surface crusting (%)	D	75.0[a]	48.0[c]
	P	42.0[b]	5.0[d]
	mean	58.5	26.5
	$LSD_{0.05}$	1.522	5.050
Depth of crust (mm)	D	38.0[a]	21.0[c]
	P	14.0[b]	8.0[d]
	mean	26.0	14.5
	$LSD_{0.05}$	2.062	2.525

D – degraded soil; P – preserved soil; n = 20 (average of the detailed data). Optimal crumb ratio of P soil: 57.3%, and of D soil: 41.4. Different letters document statistical differences between treatments

Sufficient (≥ 55%) surface cover was found to be highly useful in alleviation of the climate impact for both degraded (CSD) and preserved (CSP) soils. The least damage was sustained by soils that were subject to conservation for a long period, under adequate surface cover (CSP). The interaction between coverage and soil quality was found statistically significant ($P < 0.01$, Table 2). Knowledge of the changes in the soil quality is crucial for a meaningful description of an arable field (Ugalde et al. 2007).

The proportion of crumbs is ranked to be an important soil quality indicator. An evaluation of the relationship between the two variables of soil cover and crumb ratio by linear regression analysis (Figure 2) showed that an effectual increase in the cover ratio induces a significant increase in the proportion of the crumbs. By contrast, a low (< 20%) cover ratio entails a significantly lower rate of crumbs ($P < 0.001$). The relevant research proved that when the soil moisture content is low (0.148–0.189 g/g), the ratio of crumb is determined to a degree of 99.5% by the ratio of the covered soil surface.

Soil quality and surface treatments had significant effects on crumb ratios, surface silting and crusting ($P < 0.01$, Table 2) alike. At the end of the growing season the depth of the surface crust varied between 6–40 mm in the assessed treatments. The thickest crust developed at the BSD treatment (Table 1), where siltation was also serious, while the slight crust formed at the CSP

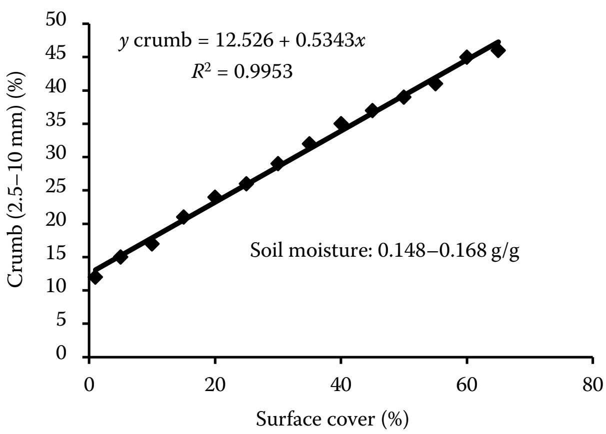

Figure 2. Surface cover impacts on crumb formation at low soil moisture state. Independent variable: surface cover, dependent variable: crumb ratio; n = 14, $P < 0.001$

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Table 2. Analysis of variance (*F*), degrees of freedom (*df*) and significance levels for soil surface deterioration

Source of variance	Crumb reduction (%)		Surface silting (%)		Surface crusting (%)		Depth of crust (mm)	
	df	*F*	*df*	*F*	*df*	*F*	*df*	*F*
Surface (A)	1	147.669***	1	3085.07***	1	4813.33***	1	622.273***
Soil (B)	1	1540.83***	1	513.966***	1	620.606***	1	160.30***
A × B	1	ns	1	14.431**	1	15.150**	1	36.667***

**P = 0.01; ***P = 0.001; ns – non-significant; n = 20. Statistical analysis covers the final result of the measurements

soil. Gallardo-Carrera et al. (2007) described 11 categories of crust, forming on an Orthic Luvisol, ranging from 2–20 mm in thickness. Baumhardt et al. (2004) observed a thin (5.5–10.9 mm) crust in the seedbed surface in a Pullman clay loam soil. Surface cover significantly reduced the thickness of the surface crust (P < 0.001) at any examined treatment. It seems that crust formation needs to be regarded as a type of damage that occurs frequently. Knowledge of the aggregate ratio that can be turned into silt that is produced after a short time abundant rainfall can help make preliminary estimates. Small aggregates, mainly the dust (< 0.25 mm) were found to be the most vulnerable. Based on this concept the crust formation was evaluated by linear regression analysis (Figure 3), in which surface cover and the amount of dust formed in the top layer were used as independent variables. In the wake of the analysis the standard error (SD) of surface crusting could be explained to a degree of 99.8%. Changes of the dust ratio in the surface layer had a three times great influence on the changes of the surface crust than did changes of the surface cover. At the same time, the crust reducing effects of a higher (≥ 50%) surface cover ratio and a lower proportion (< 15%) of dust could statistically be proven (P < 0.001). A lower (< 30%) cover ratio may increase soil exposure to the degrading processes, including siltation and crust formation. For this reason the optimal ratio of the surface cover may be a matter in dispute (Shen et al. 2012).

Climate induced physical soil defects in the deeper soil layers. Serious crumb degradation was assessed by Bottlik et al. (2014) in the rainy season, accompanied by dust leaching by infiltrating water, along with growing compaction. Both new and further measurement results truly confirmed the results achieved previously. During that season the earlier thin (≤ 5 mm) compact pan increased to 5–74 mm towards the surface. This is assumed to be related to the different dust content ratios in the surface soil and the ratios of the deposited dust. The earlier surveys (Kalmár et al. 2013b) had led to conclusion that strong clod formation can occur by deeper tillage that the loosened thick tillage pan. This was clarified by examining the correlation between the thickness of the compact layer and the ratio of clods (> 30 mm), as two variables, using the method of linear regression analysis in a dry season following a rainy one, at 0.138–0.168 g/g soil moisture content (Figure 4). Breaking up the compact pan by ploughing or loosening the ratio of large clods varied in the 10–85% range per unit quantity of tilled soil. The growing thickness of the tillage pan increased the ratio of clods significantly (P < 0.001). In case of the negligible degree of compaction (< 10 mm) ratio of clods formation was found to be significantly lower. In this relation the ratio of the clods can be determined by the thickness of the compact layer to a degree of 99.5% at lower (14.8–16.8 g/g)

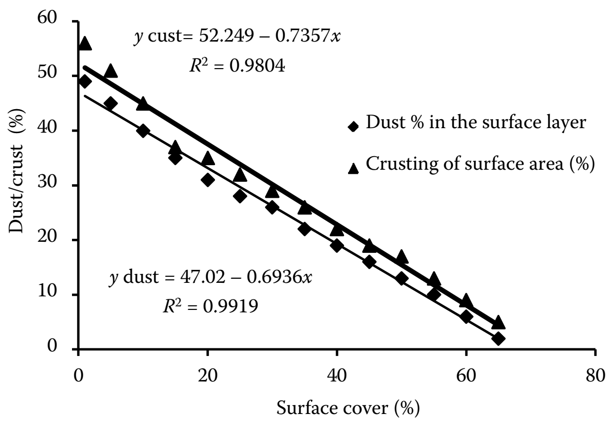

Figure 3. Surface cover impacts on dust formation in the tilled layer and on surface crust formation. Independent variable: surface cover and dust, dependent variable: crusted area; n = 14, P < 0.001

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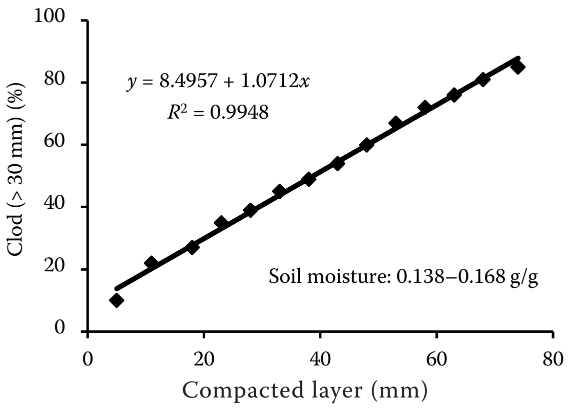

Figure 4. Impact of compacted layer extension on the large (> 30 mm) clods at low soil moisture content. Independent variable: thickness of compacted layer, n: dependent variable: ratio of large (> 30 mm) clod; n =14, $P < 0.001$

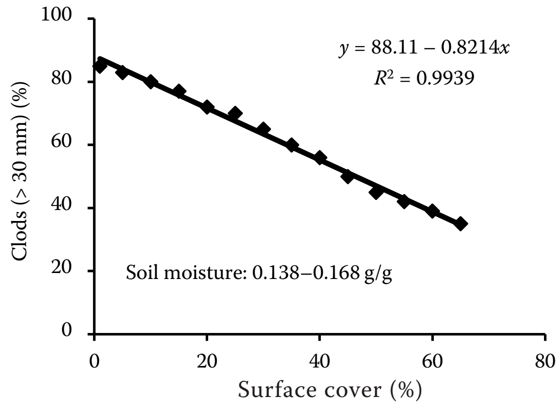

Figure 5. Surface cover impacts on the large (> 30 mm) clods at low soil moisture content. Independent variable: ratio of surface cover, dependent variable: ratio of large (> 30 mm) clods; n = 14, thickness of the compact layer: 63–74 mm; $P < 0.001$

moisture content. Solutions for preventing the consequences of dust formation were offered by Baumhardt et al. (2004) for the seedbed and by Kalmár et al. (2013a) for stubble fields.

The impacts of the surface cover in this reference soil deteriorated by the thick (63–74 mm) compact layer were also evaluated. Increasing cover rates were statistically ($P < 0.001$, Figure 5) proven to reduce the ratio of large clods even in the dry soil (0.138–0.168 g/g). Changing in clod ratio can be determined by the changing in surface cover to a degree of 99.4% at low moisture content. A close correlation ($P < 0.001$) was also stated between clod and surface cover ratio (between an insufficient 10% and an effective 55–65%).

In conclusion, the various types of mechanical stress endangering soils may grow even worse during extreme seasons. Soil state defects that are formed in dry period result in even more serious phenomena in the next rainy season. However, structure degradation that tends to occur during wet season will result in increased difficulties if it is followed by a dry year. Since tillage without damage is impossible in both wet and dry soils, prevention steps may come to play an increasingly important role.

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