The Role of Surface Sealing and Crusting in Soil Erosion

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Abstract: Surface properties play an important role in soil erodibility and in the process and volume of surface runoff. The objectives of the present paper are (1) to investigate changes of the soil structure, especially of surface characteristics in the vegetation period, (2) to measure the role of surface crusting in soil erodibility, (3) to characterize the morphology and the physical properties of the surface crust.

The applied methods include the following steps. Porosity, bulk density and infiltration measurements were carried out before and after seedbed preparation, in the initial phase of plant growth and after the harvest. The results of these measurements identify infiltration values to be expected throughout the year, not taking the influence of individual rainfall events on soil surface structure into account. As infiltration and runoff are influenced by changes in soil surface characteristics, the second methodological step involved the investigation of changes in soil surface characteristics before, during and after a rainfall event by applying rainfall simulation experiments. Rainfall simulation was repeatedly performed on the dried-out surface, i.e. after the development of the surface crust.These experiments proved that the crust reduces infiltration and increases runoff and sediment load. Two types of the crust, i.e. basin-like and hill like crusts having different surface properties were identified.

Keywords: soil erodibility, surface sealing and crusting, rainfall simulation

1 Introduction

Characteristics of the soil surface layer are of crucial importance for runoff, infiltration and soil erosion. These characteristics are in most cases different from those of the soil below. Surface sealing and crusting are the main processes responsible for this difference.

Sealing and crusting phenomena were dealt with in several studies (see e.g. Poesen & Nearing, 1993). According to Imeson and Kwaad (1990) as a consequence of different responses of the soil to rainfall, in terms of runoff and erosion, the relationship between rainfall, runoff and erosion can be very varied. Luk at al. (1990) carried out experiments on a cultivated loess soil in China and they found that because of crusting and sealing runoff was enhanced by up to 1.85 times, but the soil loss ratio of crusted and uncrusted surfaces ranged from 0.65 to1.49.

Parameters influencing soil crusting dynamics (see e.g. Poesen & Govers 1985) include various physical and chemical soil properties. Organic matter content, clay content and exchangeable sodium percentage are of particular importance (Le Bissonnais & Bruand 1993).

Soil properties change over the vegetation period, mainly because of tillage operations, changing plant cover on the surface and changing soil moisture conditions. There are also short term influencing factors like e.g. a rainfall event. Being aware of this the first question to be answered is how physical properties change over the year and the second question concerns those fine changes of shorter time periods connected to precipitation events.

The main objectives of this paper include (1) the study of changes in physical properties of topsoil (cultivated layer, i.e. cca. the upper 30 cm) over the vegetation period, (2) investigations on the role of surface crusting by rainfall simulation experiments and (3) on the morphology and physical properties of the surface crust. The investigations were carried out in Lake Balaton catchment, on a cambisol.

2 Methods

Porosity conditions and bulk density were chosen to characterize the topsoil. They are crucial for infiltration and easy to determine.

For the study of soil structure changes during the vegetation period four cultivation (plant growth) phases were selected, i.e. (a) stubble field (late summer), (2) after chiseling (autumn), (3) after ploughing (carried out in autumn, but the samples were taken in spring so that they reflect the influence of freezing and thawing in the winter as well), (4) seedbed conditions (late spring - early summer, after disking). Two samples were taken in each case. One from the upper 0 cm —7 cm and another one from the bottom of the ploughed layer, from a depth of 25 cm — 31 cm.

The samples were taken by a 100 cm^3 cylinder. The mass of the topsoil was determined first. After saturating it by water the mass was measured again. After letting gravitational water to drop out from the sample it was weighted, then dried at 105°C and weighted. Gravitational and capillary/adsorption porosity were then determined.

The study of the effects of crust formation on infiltration by using a rainfall simulator dates back to 1958 (McIntyre 1958). The Pannon 02 simulator was used to investigate surface crusting. The simulator sprinkles over an area of 24 m^2. The experimental plot has an area of 12 m^2. The drop of the spray simulator is formed by a VEE-JET 80150 type nozzle, under 41 kPa pressure. The drops falling from a height of 3 m have a kinetic energy value, which is almost identical with that of a natural rainfall. Rainfall intensity can be regulated between 30 mm/hour — 130 mm/hour.

Physical properties of the crust were determined by measuring porosity/infiltration of the crust and of the soil below. Compaction of the crust was tested by a penetrometer.

3 Results

3.1 Porosity/infiltration measurements

(1) It is interesting that the greatest porosity values could be detected in the top soil of stubble field (Fig.1). The greatest porosity value can normally be measured on a field after seedbed preparation. The reason for this can be either the application of not proper cultivation methods and/or optimal microbial and worm activity during the summer accompanied by the best possible water and heat supply conditions.

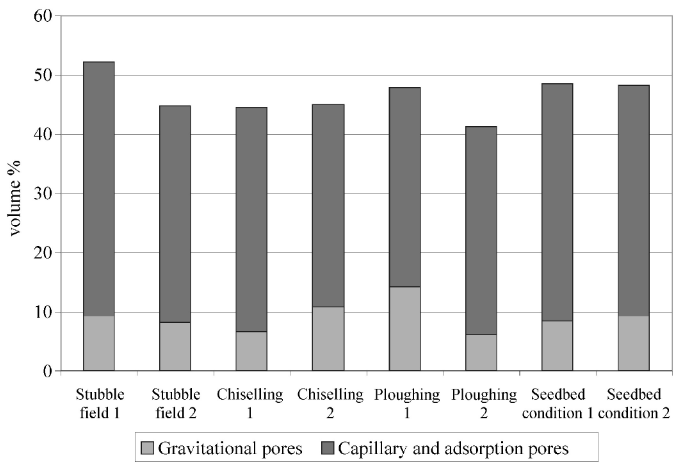

Fig.1 Porosity conditions after different cultivation/plantgrowth phases. Number 1 refers to the upper 0 cm — 25 cm, Number 2 to 27 cm — 32 cm (ploughsole layer)

(2) Samples taken form the compacted ploughsole layer at the bottom of the ploughed soil have in most cases lower porosity values than the uppermost soil layer. The only exceptions are samples taken after chiselling reflecting the positive influence of this operation.

c) Gravitational pores have the greatest value in the upper ploughed layer (ploughed 1). It should be mentioned that ploughing brings about the ploughsole layer (ploughed 2). Chiselling has a positive influence on the gravitational pores.

Bulk density measurements (Fig.2) support the above statements.

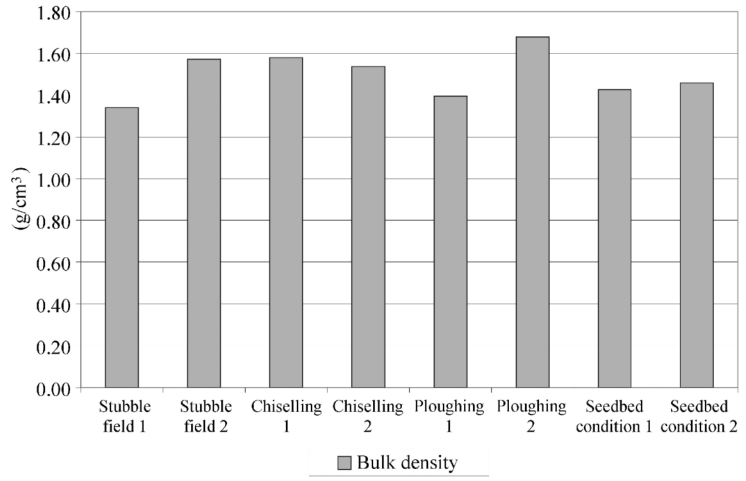

Fig. 2 Changes of bulk density after different cultivation/plantgrowth phases. Number 1 refers to the upper 0 cm —25 cm, Number 2 to 27 cm—32 cm (ploughsole layer)

3.2 Investigations on surface crusting

Rainfall simulation experiments were applied to study the process of surface crusting and its role in surface runoff and erosion. The research site is situated in Keszthely, near Lake Balaton in the vineyard of the Georgikon Agricultural Faculty of Veszprém University on a hillslope with 12.33 % gradient, covered by cambisol. The slope was cultivated by disking just before the experiment. Table 1 contains the most important characteristics of the topsoil.

Table 1 Some chemical and physical properties of the topsoil

$CaCO_3$ %	0
Humus %	1.08
pH	6.7
< 0.002 mm	12.1
0.002 mm — 0.005 mm	7.1
0.005 mm — 0. 01 mm	7.6
0.01 mm — 0.02 mm	8.4
0.02 mm — 0.05 mm	9.6
0.05 — 0.1	23.9
0.1 — 0.2	22.5
0.2 — 0.5	3
0.5 <	5.3

Two sets of experiments were performed, the first one just after the disking on 12 July 2001, before the formation of the surface crust (designated by 201) and the second one on 15 July 2001 under similar moisture conditions, after the formation of the crust.

The amount of the first simulated rain was 26.8 mm with an intensity of 60 mmh^{-1}. There was a small (natural) rainfall event of 6 mm was registered between the two runs (the intensity of this event is not known).

The same intensity, i.e. 60 mmh^{-1} was applied in the second experiment with an amount of 13.25 mm. Surface runoff was registered continuously during the experiment so that runoff intensity could also be determined.

A modified form of the Horton equation (Horton 1933) was adjusted to the measured values describing the dynamics of infiltration. The modified version is as follows:

$$Y = P_0 * (x - P_1) - (P_0 / P_2) * (1 - \exp(-P_2 * (x - P_1))),\text{ where}$$

Y Cummulative runoff
x Time
P_0 Constant (maximum) runoff
P_1 Time of runoff initiation (min)
P_2 Index of runoff change (min^{-1})

After the application of the equation the following values were gained (Table 2).

Table 2 Parameters of the modified Horton equation

	p0 l/min	standard deviation	p1 min	standard deviation	p2 l/min	standard deviation
201	7.2107	1.6146	10.0676	0.3614	0.0701	0.0244
202	9.8165	15.5851	2.0089	0.9779	0.0536	0.1121

The results can be explained as follows. Constant (maximum) infiltration was 7.2l min^{-1} in the first experiment allowing an infiltration of 4.8l min^{-1} and 9.8l min^{-1} constant infiltration and 2.2l min^{-1} infiltration was measured in the second case. The experiments prove the unfavourable effect of the crust very well.

Surface runoff started in the 10. minute in the first case and in the 2. minute in the second pointing to the fact that unfavourable infiltration conditions could be detected right at the beginning of the rain when the surface crust had been formed.

Table 3 shows sediment load values of surface runoff. During the second experiment higher runoff values were accompanied by higher sediment load values, i.e. surface crusting increases both runoff and sediment load. As it has already been mentioned in the introduction the results concerning the decrease, or increase of sediment load are different and cover a vide range.

Table 3 Sediment load

No. of simulation	Sediment load	
	$g \cdot l^{-1}$	$g \cdot min^{-1}$
201	8.9	16.3
202	10.6	21.9

3.3 Morphology and physical properties of surface crust

An attempt was made to remove (to cut) surface crust from the upper soil layer. According to the micromorphology two types of surface crust could be identified. The first type is the *basin-like crust* and the second is the Hill-like crust (Photos 1,2).

Bulk density was measured on several samples of the two micromorphological types (Table 4). The density of the soil is 2.85 $g \cdot cm^{-3}$.

Porosity diminished remarkably in the crust. There is significant difference in between basin-like and Hill-like crusts. Sealing is much more important in the basin-like crusts where there is even some water on the compacted bottom of the basin for some time after the rainfall event.

Table 4 Bulk density values of the crust ($g \cdot cm^{-3}$)

Original soil	Basin like crust			Hill-like crust	
1.61	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2
	2.34	2.14	2.29	1.93	1.80

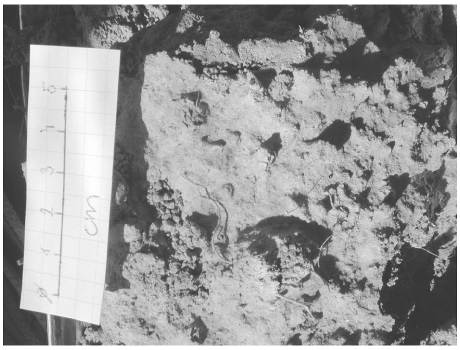

Photo 1 Hill-like crust

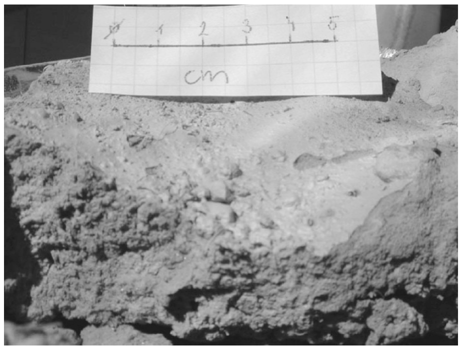

Photo 2 Cross-section of a basin-like crust

3.4 Soil resistance measurements

Soil resistance measurements by penetrometer were carried out one month after the rainfall simulation experiments.

Fig.3 presents the relationship between soil depth and soil resistance under different moisture conditions. Under wet conditions resistance as an indicator of compaction starts to increase exponentially below the depth of about 10 cm. Under dry conditions resistance is much higher and it increases gradually with depth according to a linear function.

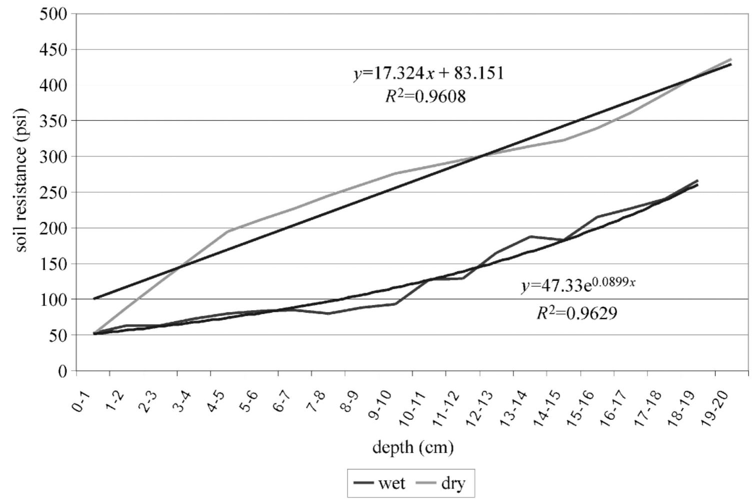

Fig. 3 Relationship between soil resistance and depth in compacted soils under dry and wet conditions (1 psi — 0.07bar)

Taking the above relationships into account it can be concluded that the decrease in infiltration capacity between the first and second simulation is not only because of the formation of the crust but also because of the sealing effect of the rain.

4 Conclusions

(1) Tillage operations and plant cover of the surface predict erosion risk over the vegetation period. Physical properties of the topsoil undergo significant changes due to the effect of precipitation events as shown in the paper.

(2) Rainfall simulation experiments proved that the crust developed on the soil surface reduces infiltration and increases both runoff and sediment load.

(3) There are two main types of crust, i.e. basin-like and hill like crusts which differ in their physical properties a great deal. Sealing is much greater in the basin-like crusts.

(4) Resistance measurements also prove that the rain has an important compacting effect on the topsoil.

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