Influence of a Compacted Subsurface Layer on Soil Erosion

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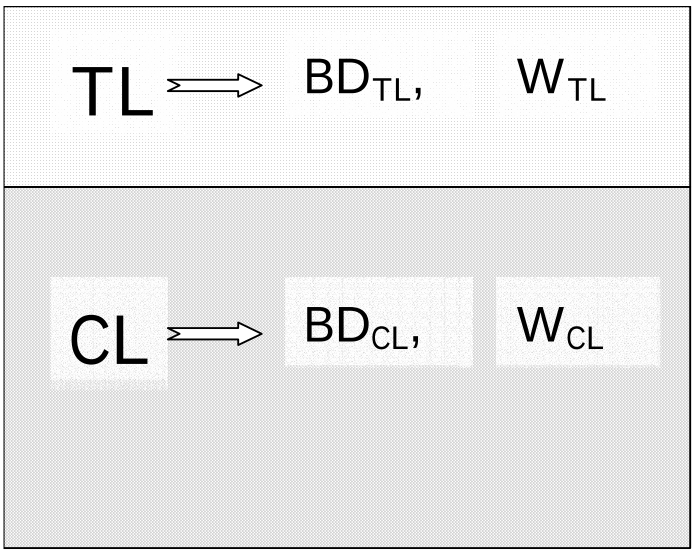
It has been recognized that water erosion of soil and soil compaction are among the major soil degradation processes in Europe. Little is known about the relationships between soil compaction and the soil erosion processes. I will discuss a mathematical model developed for estimating the influence of compacted subsurface layer formed below a shallow tillage layer on soil erosion.

The mathematical model is developed on the basis of data from field experiments with simulated rainfalls of intensities from 18 to 120 mm h^{-1} to study the influence of compacted subsurface layer caused by continuous shallow tillage on the soil erosion processes on Haplic Kastanozem. A soil with a compacted subsurface layer is represented conceptually as a media consisting of two layers – tilled layer (TL) and compacted layer (CL), which differ in their physical properties, such as bulk density (BD) and water retention (W).



Indices of compaction (I_{BD}) and soil moisture distribution (I_W) are defined to characterize the profile variability of the antecedent soil physical conditions. The index of compaction characterizes the degree of compaction by the relative change of soil bulk density in CL with regard to TL while the index of soil moisture distribution identifies the respective change of soil moisture content.

$$I_{BD} = \Delta BD = 100\,(BD_{CL} - BD_{TL}) / BD_{TL}, \qquad (1)$$

where: I_{BD} ($100 > I_{BD} > 0$) is the index of subsurface compaction, %; ΔBD is the relative increase of soil bulk density in CL with regard to TL; BD_{CL} is the value of BD in CL and BD_{TL} is the value of BD in TL.

$$I_W = \Delta W = 100\,(W_{CL} - W_{TL}) / W_{TL}\,, \qquad (2)$$

where: I_W ($100 > I_W > -100$) is the index of the soil moisture distribution profile, %; ΔW is the relative change of gravimetric soil moisture content in CL with regard to TL; W_{CL} is the value of W in CL and W_{TL} is the value of W in TL.

Considered characteristics of the soil erosion processes are the minimal rainfall impacting energy needed to initiate runoff (E_0), the sediment load per unit rainfall impacting energy (SL) and the net sediment load per 50 mm rainfall (SL_{net}). The model for estimating the influence of compacted subsurface layer formed below a shallow tillage layer on soil erosion links E_0, SL and SL_{net} (i.e. $f\,(I_{BD}, I_W, I_R)$) with the indices of compaction and soil moisture distribution, and the rainfall intensity:

$$f\,(I_{BD}, I_W, I_R)= a_0 + [a_1\,(I_W)^{\,m} + a_2\,(I_{BD})^{\,n}]\,[a_3 + a_4 \log_{10}(I_R)], \qquad (3)$$

where: a_0, a_1, a_2, a_3, a_4, m and n are parameters to be evaluated by quasi-Newton non-linear estimation fit of Equation (3) to measured E_0, SL, or SL_{net}, I_{BD}, I_W and I_R; I_R is the rainfall intensity, mm h^{-1}.

The data shown in Tabs. 1 and 2 give an idea about the value ranges of the input parameters evaluating the parameters of Eqn. (3), presented in Tab.3.

Table 1. Means and standard deviations of the input (dependent) variables for the left side of Equation (3): the minimal rainfall impact energy needed to initiate runoff (E_0), the sediment load per unit rainfall impact energy (SL) and the net sediment load per 50 mm rainfall (SL_{net}).

Intensity level	E_0 (MJ ha^{-1})		SL (t MJ^{-1})		SL_{net} (t ha^{-1})	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
I_R1[a]	5.009	6.658	0.205	0.164	2.473	1.973
I_R2[a]	4.013	5.060	1.511	0.735	17.945	13.200
I_R3[a]	1.902	2.337	3.889	0.575	48.390	14.423
I_R4[a]	1.326	1.198	7.294	1.047	94.831	23.475
I_R1[b]	1.909	2.478	0.209	0.076	2.610	0.987
I_R2[b]	2.329	3.060	0.523	0.054	6.636	2.250
I_R3[b]	1.806	2.120	1.098	0.099	13.511	4.036
I_R4[b]	1.251	1.063	2.779	0.521	36.875	6.321

[a] compaction of the layer 10-30 cm; [b] no subsurface compaction of the layer 10-30 cm.

Table 2. Means and standard deviations of the input variables for the right side of Equation (3): rainfall intensity (I_R) and the indices of subsurface compaction (I_{BD}), and soil moisture profile (I_W).

Intensity level	I_{BD} (%)		I_W (%)		I_R (mm h^{-1})	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
I_R1^a	16.3	2.6	27.0	60.3	20.1	1.8
I_R2^a	14.9	3.2	26.0	61.1	29.1	3.1
I_R3^a	14.6	4.2	26.0	61.5	52.8	6.0
I_R4^a	13.8	4.0	24.0	62.6	107.3	9.7
I_R1^b	8.4	1.1	3.3	8.5	19.7	1.3
I_R2^b	9.3	0.5	-1.6	12.3	34.5	5.1
I_R3^b	8.9	0.9	-2.2	12.9	57.9	5.5
I_R4^b	8.1	1.8	-3.6	13.8	110.2	9.4

[a] compaction of the subsurface layer 10-30 cm; [b] no subsurface compaction.

Table 3. Values of the parameters of Equation (3) obtained by non-linear fit to the measured input characteristics.

f	I_W	a_0	a_1	m	a_2	n	a_3	a_4
E_0	≥0	4.6	0.08	1	2.8	-0.8	2.9	-1.5
E_0	<0	0.46	-0.04	1	0.5	1	-0.5	0.4
SL	≥0	-0.19	0.07	1	3.58	0.2	-0.7	0.6
SL	<0	0.0	-0.32	1	0.03	2	-0.9	0.8
SL_{net}	≥0	-5.2	0.27	1	13.7	0.6	-1.3	1.03
SL_{net}	<0	-7.3	-3.3	1	0.03	3	-1.7	1.4

The plots in Fgs. 1, 2, 3 and 4 illustrate that the model shows good capability of predicting the soil erosion characteristics depending on the degree of compaction and the rainfall intensity. The estimates of E_0, SL and SL_{net}, predicted by the model for three levels of the index of soil moisture distribution and four levels of the rainfall intensity, demonstrate the basic trends of soil erosion behaviour under conditions of a compacted subsurface layer. It is established that the type of the relationships between the soil erosion characteristics and the degree of compaction depends considerably on the index of soil moisture distribution. Generally, a compacted subsurface layer affects soil erosion much more significantly when the moisture content is higher in TL than in CL. Verification of the model is needed for still broader ranges of the input soil characteristics to confirm its suitability for predictive purposes.

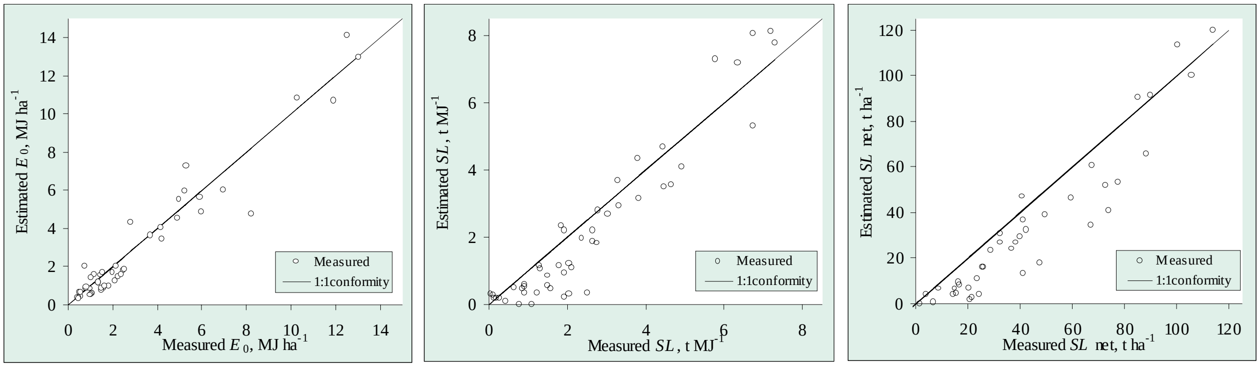


Figure 1. Soil erosion characteristics estimated by Equation (3) versus measured ones. The parameters of Equation (3) are as listed in Table 3.

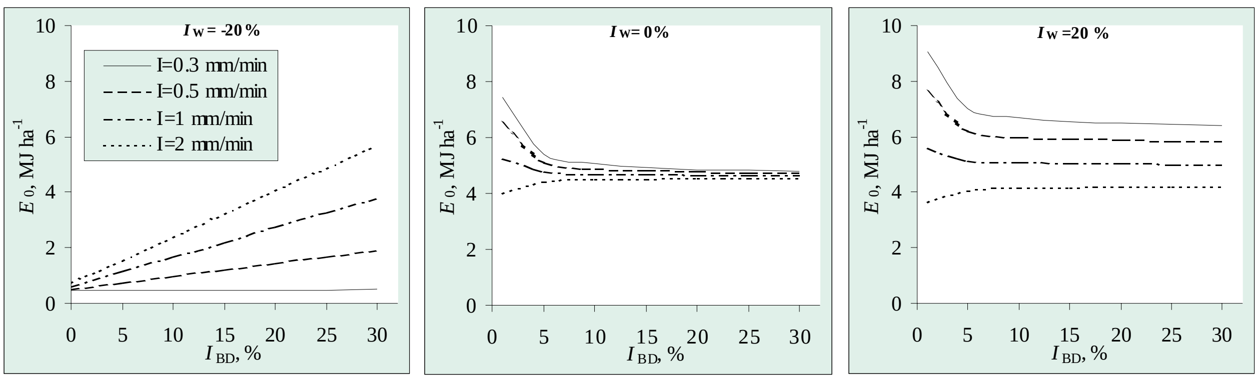


Figure 2. Predicted relationships between the minimal rainfall impact energy needed to initiate runoff (E_0) and the index of subsurface compaction (I_{BD}) for four levels of rainfall intensity (I) and three levels of the index of soil moisture distribution I_W.

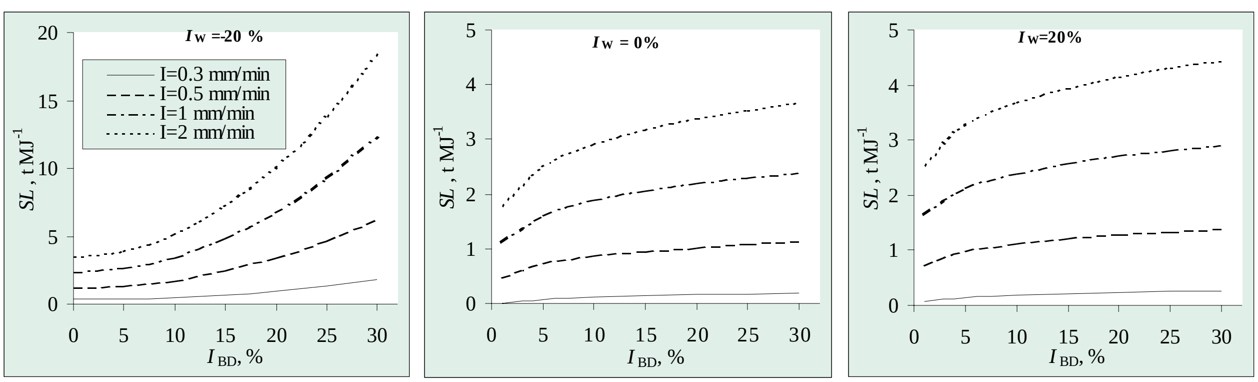


Figure 3. Predicted relationships between the sediment load per unit rainfall impact energy (SL) and the index of subsurface compaction (I_{BD}) for four levels of rainfall intensity (I) and three levels of the index of soil moisture distribution (I_W).

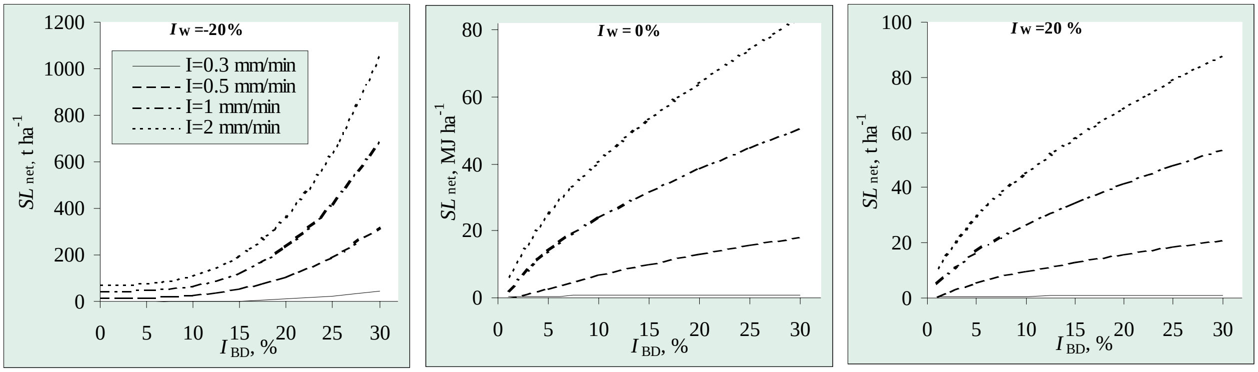


Figure 4. Predicted relationships between the net sediment load (SL_{net}) caused by 50 mm rainfall and the index of subsurface compaction (I_{BD}) for four levels of rainfall intensity (I) and three levels of the index of soil moisture distribution (I_W).