Conference Paper

Effect of Synthetic Detergents on Soil Erosion Resistance

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Abstract

The effect of soil contamination with synthetic detergents (SD) Labomid-203, MS-8 and ML-51 in combination with potassium monoborate (MBP) on the change in the potential of soil erosion resistance (PER) was evaluated. PER characterizes the soil resistance to water erosion and is equal to the energy of a water jet acting perpendicular to the soil surface, required for the destruction and removal of a unit of soil mass from the area of its natural occurrence. Soil water retention curve (SWRC) and hydraulic conductivity were selected for the research as parameters determining soil erodibility. SWRC and moisture conductivity function are dependent on the surface tension and viscosity of the moisture in the soil, which are changed on soil contamination with surfactants of washing solutions. Integrating the expression for SWRC in the range of moisture content values from a fixed initial value to the value, corresponding to the complete filling of soil pores with moisture, gave the result correlating with the energy determining the potential for erosion resistance. Soil contamination with SD and MBP led to the significant decrease in soil erosion resistance, which is particularly evident at low moisture values. The largest decrease in soil erosion resistance (by an average of 39.6%) was caused by MS-8 (1.0% MS-8, 0.3% MBP). The smallest decrease in soil erosion resistance (by an average of 12.4%) was caused by ML-51 (0.5% ML-51, 0.1% MBP). The experiments were carried out with dark-gray and light-gray forest soils of the Chuvash Republic (Russia).

Keywords: soil erosion resistance, surfactants, soil pollution, soil contamination

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Received: 24 December 2019
Accepted: 9 January 2020
Published: 15 January 2020

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the BRDEM-2019 Conference Committee.

1. Introduction

Soil pollution and soil degradation by erosion are serious global problems [1, 2]. Their solution should be comprehensive. On the one hand, soil erosion causes processes related to the migration of chemicals in soil [3]. On the other hand, the chemical composition and concentration of soil pollutants can be a factor directly affecting dynamic soil processes including erosion [4]. In particularly, results [5] showed that the lead pollution increased soil erodibility. In the case of uncontrolled discharge of household waste into waterways and arable land areas, synthetic detergents (SD) can make up a significant part of pollutions [6--8]. SD are poorly biodegradable pollutants

How to cite this article: Sergey Chuchkalov, Ivan Fadeev, Victor Alekseev, and Boris Mikhailov, (2020), ``Effect of Synthetic Detergents on Soil Erosion Resistance'' in *International applied research conference «Biological Resources Development and Environmental Management»*, KnE Life Sciences, pages 489--496. DOI 10.18502/kls.v5i1.6113

consisting mainly of two components, one of which (sulfonate) is a surfactant, and the other, the carrier, is mainly in the form of polyphosphates or other substances [9].

Adequate quantitative assessment of soil erosion properties is necessary to predict possible soil degradation and develop a set of measures to prevent it. In this paper, an attempt is made to evaluate the effect of synthetic detergents on the change in soil erosion resistance. Special attention was paid to water erosion, namely, soil wash-out by water flow. From a wide range of properties (biogenicity, humus content, chemical and mechanical composition, carbonate content, etc.) that determine soil erodibility, the hydrophysical parameters of the soil, such as soil water retention curve (SWRC) and hydraulic conductivity, were selected for the research. The SWRC is the relationship between the capillary-sorption pressure of moisture and soil moisture and hydraulic conductivity of the soil characterizes the speed and direction of soil moisture movement [10]. It is these functions that make it possible to qualitatively and quantitatively evaluate the potential of erosion resistance of the soil. Erosion resistance potential E (J/kg ≡ m^2/s^2) is the energy of a water jet acting perpendicular to the soil surface, required for the destruction and removal of a unit of soil mass from the area of its natural occurrence:

$$E = \frac{\Delta W}{m_s}, \tag{1}$$

where ΔW is the energy spent on the destruction and removal of a soil sample of mass m_s.

Considering that the destructibility of soil structures depends not only on the impact energy, but also on duration Δt of its exposure, the specific power P (J/(kg·s) ≡ m^2/s^3) can be also used, that is the ratio of the erosion resistance potential to the time of impact of water jet on the soil, to characterize erosion resistance:

$$P = \frac{E}{\Delta t} = \frac{\Delta W}{m_s \cdot \Delta t}. \tag{2}$$

In the work [11] the effect of surfactants addition in washing solutions on change of contact angles of wetting was considered, and a multifactorial power-law dependence of the contact wetting angle on the concentration of surface-active SD in combinations with potassium monoborate (MBP) was obtained. Since the SWRC and the moisture conductivity function, which determine soil erosion resistance, are functionally dependent on the surface tension and viscosity of the moisture in the soil, they are used in this research.

2. Methods and Equipment

In a first approximation, we assume that the soil resistance to erosion is determined by the forces hold the soil particles together and the rate of soil wetting. The hydraulic conductivity of the soil characterizes the movement speed of soil moisture polluted with detergent, and therefore determines the rate of soil wetting. The dependence of hydraulic conductivity *K* (moisture conductivity) on volumetric soil moisture content *w* is expressed as follows [12]:

$$K = \frac{\pi^2}{\Omega_0 \eta S^2} \cdot \frac{\lambda \Pi_0^{2.5}}{1 - \Pi_0} \cdot \left[1 - \left(1 - \frac{w}{\Pi_0}\right)^2\right], \tag{3}$$

where η is water viscosity, (Pa·s); *S* is cross-section area of soil sample the water flows through (m^2); *w* is volumetric water content, (m^3/m^3); λ is dimensionless coefficient; Π_0 is the porosity of the dry soil sample (m3/m3).

The SWRC determines the total potential ψ of soil moisture including the potential ψ' due to the interaction of moisture with the solid phase of the soil, and the potential ψ'' due to the interaction of moisture with the soil air. Thus, the SWRC determines the forces that hold the soil particles together. The dependence of the total potential ψ of soil moisture on the volumetric moisture content *w* of the soil has the form [12]:

$$\psi = \psi' + \psi'' = \frac{A\Omega_0^3}{\rho} \cdot \left(\frac{1}{w^3} - \frac{1}{\Pi_0^3}\right) + \frac{\Omega_0 \sigma_{\mathrm{lg}}}{\rho} \cdot \left(1 - \frac{w}{1 - \Pi_0 + w}\right) \cdot \left(1 - \frac{w}{\Pi_0}\right)^{2.5}, \tag{4}$$

where Ω_0 is volumetric specific surface, (m^2/m^3); *w* is volumetric moisture content, (m^3/m^3); σ_{lg} is specific free surface energy at the water/air boundary (J/m^2); ρ is water density (kg/m^3); *A* is the dimensional constant (J).

Consider two elementary soil particles held together by soil moisture. There is the area of contact of moisture with the solid phase of the soil and the area of contact of soil moisture with the gas phase (soil air). Expression (4) characterizes the potential and pressure of soil moisture at a certain value of moisture content. If the moisture content in the system increases, then the potential and pressure decrease. When the pores are completely filled with water (porosity can be considered as the maximum moisture content in the soil), the contact area of soil moisture with the gas phase becomes zero. Under this condition, soil particles become ``free'' and can be caught by the water stream. Integrating the expression (4) in the range of moisture content values from a fixed initial value *w* to the value $w = \Pi_0$, corresponding to the complete filling of soil pores with moisture, gives the result that correlates with the energy ΔW, which determines the potential for erosion resistance:

$$E(w) \sim \int_w^{\Pi_0} \psi(w)\, dw. \tag{5}$$

The expression (5) allows revealing the dependence of soil erosion resistance on moisture content, as well as to study the influence of detergents on the change of soil erosion resistance.

The SWRC and moisture conductivity function were obtained by the method described in [12]. The erosion resistance potential was measured at various values of volumetric moisture content of soil by the method described in [13, 14]. The volumetric moisture content was determined by conventional methods (in particular, gravimetric method of moisture content determination). As synthetic detergents Labomid-203, MS-8 and ML-51, which are a mixture of surfactants with electrolytes -- sodium salts of carbonic, phosphoric and cream acids and intended for degreasing of a metal surface from conservative lubricants and removal of operational contaminants [15], were used in experiments. In practice, the addition of MBP to these detergents increases their wetting ability for contaminations such as carbon and oil-resinous deposits.

3. Results

The experiments were carried out with light-gray forest soils (average volume weight of 1.34 g/cm^3) of oak forests of the Tsivilsky district of the Chuvash Republic (Russia). Data on the change in contact angles of wetting of soil moisture depending on the MBP concentration in combination with SD are given in Table 1. Data on the change in the potential of soil erosion resistance depending on the concentration of MBP in combination with SD are shown in Table 2.

TABLE 1: Dependence of the wetting angle θ on concentration of SD and MBP.

wetting angle θ, degrees						
MBP, %	**Labomid-203, %**		**MS-8, %**		**ML-51, %**	
	0.5	**1.0**	**0.5**	**1.0**	**0.5**	**1.0**
0.1	67.2	64.2	57.6	55.2	71.8	70.5
0.2	62.2	60.3	56.1	52.4	66.9	64.6
0.3	59.8	59.2	50.1	49.5	63.5	61.2

TABLE 2: Change ΔE in erosion resistance potential of soil under contamination by SD and MBP.

ΔE, J/kg						
MBP, %	**Labomid-203, %**		**MS-8, %**		**ML-51, %**	
	0.5	**1.0**	**0.5**	**1.0**	**0.5**	**1.0**
0.1	0.45	0.54	0.74	0.82	0.31	0.35
0.2	0.60	0.66	0.79	0.90	0.46	0.53
0.3	0.68	0.70	0.97	0.99	0.56	0.63

The curves of the dependence of the erosion resistance potential on the moisture volumetric content calculated according to formula (5) and the experimental points for light-gray forest soil are presented in Figure 1. The curve 1 in Figure 1 shows the dependence of the erosion resistance potential on the moisture volumetric content for ``clean'' soil. The curve 2 in Figure 1 shows the dependence of the erosion resistance potential on the moisture volumetric content for soil contaminated with SD and MBP (1.0% MS-8, 0.1% MBP). The difference in the position of the curves 1 and 2 in Figure 1 reflects the effect of SD and MBP on soil erosion resistance.

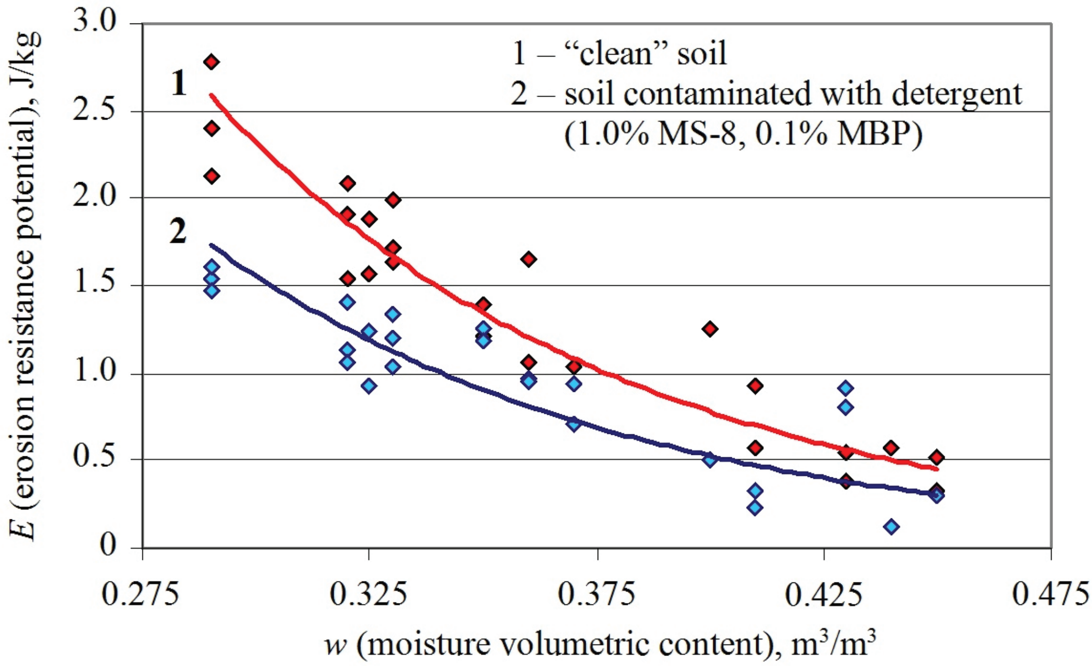

Figure 1: Dependence of the erosion resistance potential on moisture volumetric content for light-gray forest soil.

4. Discussion

With increasing soil moisture, regardless of the presence and level of soil contamination, soil erosion resistance decreases. When the moisture content increases the potential of erosion resistance tends to minimal limiting value corresponded to the residual kinetic energy of the washed-out soil flow.

Soil contamination with SD and MBP leads to the significant decrease in soil erosion resistance, which is particularly evident at low moisture values. The largest decrease in soil erosion resistance (by an average of 39.6% of the natural state of the soil) was caused by MS-8 contamination (1.0% MS-8, 0.3% MBP). The smallest decrease in soil erosion resistance (by an average of 12.4% of the natural state of the soil) is caused by

ML-51 contamination (0.5% ML-51, 0.1% MBP). In all studied cases, even a small increase in the concentration of both SD and MBP leads to a noticeable decrease in the erosion resistance of contaminated soil. Soil contamination with SD and MBP even at their low concentrations (not more than 1%) in washing solution significantly decreases the soil erosion resistance.

5. Conclusion

Soil contamination with SD such as Labomid-203, MS-8 and ML-51 in combination with MBP, even at their low concentrations (not more than 1%) in washing solution significantly decreases the soil erosion resistance. It was experimentally found that the decrease in the erosion resistance potential of light gray forest soils of the Tsivilsky district of the Chuvash Republic (Russia) varies on average from 12.4% to 39.6% depending on the type of SD and the concentration of the contaminating washing solution. The largest decrease in soil erosion resistance was caused by MS-8 contamination (1.0% MS-8, 0.3% MBP).

The results of measurements of the erosion resistance potential are consistent with numerical calculations of its values based on the model that takes into account soil hydraulic conductivity and the interaction of moisture with the solid phase of the soil and the soil air. Integrating the expression for SWRC in the range of moisture content values from a fixed initial value to the value, corresponding to the complete filling of soil pores with moisture, gives the result correlating with the energy determining the potential for erosion resistance.

A quantitative assessment of soil erosion properties allows predicting possible soil degradation and developing a set of measures to prevent it. The results obtained indicate the need to take into account the effect of contamination on soil erosion processes when developing measures for the reclamation of derelict and contaminated land.

Conflict of Interest

The authors have no conflict of interest to declare.

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