SOIL EROSION

Destruction of Soil Aggregates in Slope Flows


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Abstract—Field studies and model experiments, as well as theoretical considerations, suggest that bed sediments represented by soil aggregates in overland flows on slopes exert a considerable influence on the intensity of erosion processes. In this context, one of the key problems in the development of adequate erosion models is the problem of the rate of destruction of such aggregates in the flows. The results of experimental studies of the destruction of aggregates of chernozemic soils are analyzed. It is found that the destruction of soil aggregates in the flow proceeds in two stages. During the first stage, the aggregates are rapidly broken apart into smaller fragments. During the second stage, these fragments are subjected to abrasion. An equation describing the destruction of aggregates upon their movement in the flow in dependence on the aggregate size and the distance of aggregate transport is suggested. The effect of some groups of soil microorganisms on the aggregate resistance to the destruction is shown.

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INTRODUCTION

Changes in the economy and technology of agricultural production and the general increase in technogenic loads on the environment affect our views on different aspects of soil erosion. Traditionally, soil erosion is considered as a process leading to a decrease in the soil fertility. In recent decades, the problems related to environmental pollution by the chemical and biological substances contained in eroded sediments have come to the forefront of erosion studies. These are two different, though interrelated problems. Thus, in the context of the loss of soil fertility, the particle-size and aggregate-size distributions of sediments transported by overland flows on slopes are not very important. In the context of environmental pollution, these are the key parameters, as they determine the distance of transportation of different sediments by flows. Moreover, various experiments have proved that the properties of soil aggregates and, particularly, their stability in overland flows are factors that affect the intensity of soil loss from erosion.

It is known that the rise in the intensity of soil erosion upon an increase in the slope length generally decreases. In the statistical models of soil erosion, this decrease is reflected by the exponent value of the slope length term (the exponent is less than 1.0). In the models based on the physical considerations, this decrease is usually related to the accumulation of a sediment load in the flow: it is argued that the flow energy is partly spent on the transportation of these sediments, so that the energy of the particle detachment from the flow bed decreases. According to Foster with coauthors [14], the intensity of soil erosion decreases proportionally to the difference between the carrying capacity of the flow and the sediment load in it. These authors did not distinguish between the suspended sediments and the bed load. At the same time, there are data about the effect of the sediment concentration in the entire flow and in the near-bottom flow layer on the carrying capacity of the flow. It is important that the concentration of sediments in the near-bottom layer (bed load) depends on the particle-size distribution of the transported sediments; in relation to overland flows on slopes, it depends on the size of the transported soil aggregates [17]. Mirtskhulava [10] argued that the washout of sediments by slope flows is only replaced by sediment accumulation upon a considerable decrease in the slope steepness, so that the amount of sediments in the overland flows on real slopes remains below the values corresponding to the carrying capacity of the flows. Thus, he concluded that the effect of transported sediments on the erosive potential of the flows could be neglected.

One of the assumptions lying at the base of the hydrophysical model of erosion processes is an assumption about the relationship between the erosive capacity of the flow and the concentration of the bed load [6]. This assumption is based on the fact that the relative decrease in the erosion intensity down the slope on chernozemic soils is more pronounced in comparison with that on slopes with chestnut and soddy-podzolic soils [5]. It is reasonable to explain this fact by the differences in the degree of soil aggregation and aggregate stability in the studied soils. As both parameters are higher in the chernozems, the portion of aggregates in the bed load of the flow on the chernozemic soils should be higher than that in the flows over the chestnut or soddy-podzolic soils. The mathematical simulation also proved that the intensity of the particle detachment...
by the flow should be inversely proportion to the amount of bed load. Later, this hypothesis was experimentally verified in erosion chutes; it was shown that near-bottom sediments (bed load) decrease the intensity of soil erosion [7].

Thus, the total amount of sediments in the flow and the relationship between the suspended and bed loads may affect the general intensity of the erosion; the distribution of erosion intensities along the slope; and, probably, the transporting capacity of the flows. In relation to this, the effect of abrasion of soil aggregates transported by the flows is of great interest. Shvebs [11] was the first to study the abrasion of aggregates from southern and ordinary chernozems in an erosion chute; he described the main features of the abrasion process. The experiments performed by Shvebs were aimed at studying changes in the hydraulic radius of soil particles (aggregates) in dependence on the distance of their transportation. However, they did not answer the question about the effect of the bed load on the intensity of the soil erosion. In our study, we concentrated on the processes of abrasion of soil aggregates carried by overland water flows and on the effect of some biochemical factors on the aggregate stability in the flows.

OBJECTS AND METHODS

The abrasion of soil aggregates was studied in a hydraulic chute with a length of 10 m and a bottom width of 0.1 m. To imitate the natural roughness, the chute bed was pasted over with gravel (0.3–1.0 cm in diameter), above which a mixture of loam with a polyvinyl glue was applied. This mixture of viscous consistency filled the spaces between the gravel and covered them with a continuous thin film. Thus, a surface imitating the roughness of natural flow beds on slopes was created. The hydraulic parameters—slope steepness, water discharge, flow depth (1 cm), and the average velocity of the flow (90 cm/s)—were the same in all the experiments.

Samples from the plow horizon of a heavy loamy leached chernozem of the Volovskii district of Tula oblast were used in the experiments. The soil was air-dried and sieved through screens with mesh sizes of 10 and 1 mm. The aggregate fraction of 1–10 mm was capillary wetted for 12 h and then sieved through a screen with a mesh size of 1.66 mm (the method of wet sifting according to Savvinov). The water-stable aggregates that remained on the screen were air-dried; aggregates with characteristic sizes of 5, 3, and 2 mm were obtained from them (10 aggregates of every size class). They were weighed with an accuracy of 0.001 g and placed on filter paper apart from one another. Water was applied from beneath the paper to soak the aggregates for 12 h.

Then, the aggregates were washed off from the paper with a weak stream of water into the flow at the head of the chute; at the end of the chute, they were captured on a sieve with a mesh size of 0.25 mm. The aggregates from this sieve were washed off into a porcelain bowl; the excess water was decanted. After this, the aggregates from the bowl were washed off into the flow at the head of the chute once again. These operations were repeated until the total length of the transportation of the aggregates by the water flow in the chute reached certain preset values for every series of the experiment: 10, 20, 50, 100, 150, and 200 m. The duration of the movement of the aggregates along the chute (10 m) was registered. Photos of the aggregates carried by the flow in the chute were made. After the end of the experiment, aggregates from the bowl were placed on a filter, air-dried, and weighed. The difference between their initial and final weights was considered as the loss of aggregates under the impact of their abrasion and destruction to sizes of less than 0.25 mm. Each of the experimental series was performed in 3–6 replicates.

RESULTS AND DISCUSSION

Visual observations and photos demonstrated that the destruction of aggregates in the flow proceeds in two stages. In the first tens of meters, the breakdown of large aggregates into smaller aggregates takes place. At the same time, fine suspended material appears in the flow, so that the flow turbidity increases. This material may represent the soil particles (or fine aggregates) separated from large aggregates in the course of their breakdown. It is interesting that the original granular shape (with clear edges) of the aggregates of chernozemic soils is preserved in the aggregates carried by the flow during this stage. With an increase in the distance of the aggregate transportation by the flow, the amount of aggregates coarser than 0.25 mm decreases. The remaining aggregates are subjected to gradual abrasion, and their edges become rounded. Finally, the remaining aggregates acquire a spherical or elliptical form.

Thus, in the course of transportation of the aggregates by the flow, two stages of their disintegration can be distinguished: (a) the stage of predominant breakdown into smaller aggregates accompanied by some abrasion of the aggregates and (b) the stage of aggregate abrasion proper. This combination of two processes (breakdown or destruction of aggregates and their abrasion) is not specific to soil aggregates. The same processes are observed upon the transportation of rock fragments in rivers. The fragments are subjected to both abrasion and disintegration under the impact of their collisions, especially in places with increased flow velocities [8]. Two stages in the destruction of soil aggregates were also noted by Shvebs [11]. In his experiments, the “explosive” breakdown of the aggregates was observed during the first 100–150 m of their movement in the flows. In our experiments with the leached chernozem, the first stage was shorter: the breakdown of the aggregates into smaller aggregates...