Spatial Features of Erosion and Soil Properties on Slopes with Different Exposure (Assessment by Magnetic Tracer Method)

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Abstract In the key sites in forest-steppe zone of the Eastern European plain (in Tula, Kursk and Tambov regions) were studied pairs of arable slopes with same shape, length and other morphology parameters but different exposure. Revealed that soil erosion on the south facing slopes was higher than on the same morphology slopes north exposition. The differences between the rates of soil erosion on the arable slopes of southern and northern aspects for relatively steep surfaces was from 2.5 to 6 times. For gentle slopes it appears less then 1.5 times. Differences of soil erosion rates resulted in differences of soil organic carbon (SOC) concentrations, which was less in soils on south facing slopes than on north. On gentle slopes SOC concentrations were the same on slopes with different exposure. Also soils on south facing slopes characterized by high coefficient of variation of SOC against north facing slopes. Investigations of the whole watershed in Tula oblast didn’t revealed clear trend between rates of soil erosion and exposure, because of asymmetric shape of the watershed and different morphology of the opposite slopes. But despite of obvious links between the rates of erosion and exposition of slopes of the watershed SOC concentrations and coefficient of variation of SOC had the same trend revealed for the other key sites.

Keywords: exposure, magnetic, tracer, method, soil, erosion, accumulation, arable

1. INTRODUCTION

It is known that one of the important factor of soil erosion is the exposure of slopes. Publications about soil erosion on slopes with different exposures are not numerous (Braude, 1976; Badmaev, Dugarov, 1991; Gennadiev et al., 2010; Golosov, 2006; Kulikov et al., 1996; Luchickaya, Bashkin, 1994 and others), but all researches in forest-steppe zone claim that soil erosion on slopes of south exposure is more intensive than on north. Reason of these differences is connected with character of snow melt. On “warm” south exposures snow melt is more intensive than on slopes of north exposure which lead to more intensive water streams and soil erosion. Also great significance for soil erosion during spring period determined by combinations of melt and rain washout on not covered slopes. On south facing slopes snow melting starts earlier and these slopes remain not covered for longer time periods, so it leads to more risks of high intensive erosion events on south facing slopes than on north facing slopes (Braude, 1976; Golosov, 2006).

Slopes exposure also influence on soil properties, mainly on soil productivity, humus reserves, depth of soil genetic horizons, density and so on. Partly soil properties are connected with processes of erosion and accumulation. Partly differences of soils on opposite slopes are connected with differences of factors of pedogenesis which are connected with differences of intensity of plant performance, humidity, solar insolation, specific micro-bacterial communities and so on (Badmaev, Dugarov, 1991; Gennadiev et al., 2010; Kulikov et al., 1996; Luchickaya, Bashkin, 1994; Shiriniyan et al., 2009).

It seems important to obtaining new quantitative data of erosion and soil properties on slopes with different exposure together within the same objects, for the purpose of understanding the role of erosion-accumulation processes on forming of soils and soil cover.
2. OBJECTS AND METHODS

Intensity of erosional processes and soil properties on the slopes of different aspects studied at 4 key sites, located within forest-steppe zone in the Eastern European plain: the Tolmachi site in Tambov oblast, the Gracheva Loshchina site in Kursk oblast, the Aleksandrovka site and the Plavsk site in Tula oblast (table 1).

<table>
<thead>
<tr>
<th>No</th>
<th>Site (region)</th>
<th>Slope form, length and steepness</th>
<th>Annual precipitation, mm</th>
<th>Soil forming rocks</th>
<th>Soils</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tolmachi (Tambov oblast)</td>
<td>Convex, 450-600, 3°</td>
<td>450-470</td>
<td>Calcareous loess-like loams</td>
<td>Medium-thick loamyleached and typical chernozems</td>
</tr>
<tr>
<td>2</td>
<td>Gracheva Loshchina (Kursk oblast)</td>
<td>Convex, 500-600, 5°</td>
<td>550-580</td>
<td>-''-</td>
<td>Medium-thick and thick loamyleached and typical chernozems</td>
</tr>
<tr>
<td>3</td>
<td>Aleksandrovka (Tula oblast)</td>
<td>Convex, 500-600, 6°</td>
<td>500-520</td>
<td>-''-</td>
<td>Medium-thick and shallow loamyleached chernozems</td>
</tr>
<tr>
<td>4</td>
<td>Plavsk (Tula oblast)</td>
<td>Convex, 300-600, 3-6°</td>
<td>570-600</td>
<td>-''-</td>
<td>Medium-thick and shallow loamyleached chernozems</td>
</tr>
</tbody>
</table>

On Tolmachi, Gracheva Loshchina and Aleksandrovka sites, studied opposite slopes with south and north aspects. To exclude other factors except exposure south and north catenas had almost the same morphology characteristics, soil cover, rocks and were close one to another. All studied slopes on these key sites were plowed, had convex shape of longitude profile, lengths 450-600 meteres. But the slopes differs much by steepness. Minimum steepness of studied slopes was in the Tolmachi site and amount to 3°, on Gracheva Loshchina site steepness was higher - 5°, on Aleksandrovka site it was maximum - 6°.

On the Plavsk site in Tula oblast studied 10 catenas within whole small watershed. Plavsk watershed has area just about 0,7 square meters and has drop-shaped form. It is not symmetric. Slopes of south exposition characterizes more extent of the slopes (about 500-600 m) than north facing slopes (about 300-400 m). All slopes have convex shape of longitude profiles. Slopes with maximum steepness about 6° are rather shot (300-400 m) and located near watershed mouth, slopes with minimum steepness – 3-4° are longer (500-600 m) and located in the most remote from watershed mouth part of the catchment.

Soil erosion was studied by rather new magnetic tracer method. This method occurred in the United States two decades ago (Jones, Olson, 1990; Hussain et al., 1998). Last 10 years magnetic tracer method develops by authors of this publication in Moscow State University, Russia jointly with colleagues from Illinois University in Urbana-Shampain, USA.

The method is based on quantitative assessment reserves of spherical magnetic particles (or SMPs) in soils. Origin of spherical magnetic particles is mainly connected with coal burning in steam engines of locomotives and thermal electric power stations. So active deposition of SMPs onto the soil surface began about 150 years ago. As shown by special studies, this source of SMPs predominates over potential natural sources, such as - volcanic eruptions, cosmic dust, first of all in the areas near the railroads. We found that the reserves of SMPs accumulated in soils decrease with an increase in the distance from the railroads.
Magnetic spheres are very small particles. They consist of magnetite and hematite minerals. SMPs are very stable and preserved in soil mass for at least hundreds of years. Main morphological specific features of magnetic spheres are their hollow concentric structure and metallic luster. These features make possible to distinguish them from other strongly magnetic minerals.

The deposition of SMPs onto the soil surface from the atmosphere within a given area has a relatively even character. Therefore, changes in concentrations of SMPs in the soil cover result from the erosion or deposition of soil matter. It is supposed that the mass of SMPs redistributed under the impact of erosion is proportional to the mass of redistributed sediment.

The quantitative assessment of soil erosion rate is based on a comparison of the concentrations of SMPs in soils on different parts of slopes relative to their concentrations on flat summits (where erosion is absent or almost absent). The lengths of the particular segments of slopes are taken into account. It is supposed that the differences in the contents of SMPs between the reference and slope soils appeared in the past 120 to 150 years (depending on time of the beginning of the active use of steam engines on railroads).

Decrease of SMP reserves on the slope position is proportional to soil matter loss, increase – deposition. The equation using to calculate the rate of soil erosion is showed below

\[ Y = 10^6 B \times D \times X : T , \]

where: \( Y \) is the rate of erosion or deposition, t/ha per year; \( B \) is the soil bulk density, kg/m³; \( D \) is the thickness of the layer sampled, m; \( T \) is the time from the beginning of the depositing SMPs onto the soil surface, years; \( X \) is the relative change in the specific pool of a tracer in the studied point \( X = (X_n - X_1) / X_1 \), where \( X_n \) is SMP reserve in the studied point n, g/m² in layer D; and \( X_1 \) is SMP reserve in the reference point, g/m² in layer D.

3. RESULTS

Conducted investigations revealed that soil erosion rate on the Aleksandrovka site on the south facing slope reached 11 t/ha per year, on the north facing slope – 2 t/ha per year; on the Gracheva Loshchina site soil erosion was 10 and 4 t/ha per year, respectively; on the Tolmachi site 6 and 4 t/ha per year, respectively (Fig. 1). Thus, at all the investigated sites, soil erosion on the south facing slopes was more intensive than that on the north facing slopes. These results, obtained for all studied key sites, confirm data presented in the previous publications of the other scientists (Braude, 1976; Badmaev, Dugarov, 1991; Gennadiy et al., 2010; Golosov, 2006; Kulikov et al., 1996; Luchickaya, Bashkin, 1994 and others).

Important to note that revealed clear trend between rates of erosion and slope steepness. The differences between the rates of erosion on the slopes with southern and northern aspects for relatively steep slopes (5° and 6°) of the Gracheva Loshchina and Alkeksandrovka sites was from 2.5 to 6 times. For gentle slopes (up to 3°) of the Tolmachi site, it decreased to 1.4 times.

For studied key sites also calculated proportion of soil matter, which accumulated inside the slopes, and soil matter, which carried out of the slopes. In the Tolmachi site on south facing slope only 5% of soil matter accumulated inside the slope, other 95% washed out; on the north facing slope 30% of soil matter accumulated inside the slope, other 70% washed out the slope. In the Gracheva Loshchina site only 11% of soil matter accumulated inside the south facing slope and 69% - inside the north facing slope. In the Alkeksandrovka site on south facing slope soil accumulation was almost absent and on north facing slope all eroded soil mass accumulated inside the slope.

So revealed links between slopes exposition and soil matter accumulations. On studied key sites on south facing slopes proportions of soil matter accumulated inside the slopes were less than 11%, other
overwhelming part of soil material washed outside the slopes. On north facing slopes proportions of soil matter accumulated inside the slopes were much more and varied from 30% to 100%.

![Graph showing soil erosion rates](image)

**Figure 1.** Rates of soil erosion The rates of soil erosion at key sites Aleksandrovka, Gracheva Loshchina and Tolmachi on slopes of different aspects

W found the certain relationships between the rates of soil erosion and deposition, slope aspects, and the concentrations of soil organic carbon (SOC) in the plow horizons. The organic carbon content in the soils of intensely eroded south facing slopes was considerably lower than that in the soils of less eroded north facing slopes. Thus at the Aleksandrovka site SOC concentration was 3.7% on south facing slope and 4.1% - on north facing slope; at the Gracheva Loshchina site SOC concentration was 3.5% on south facing slope and 3.6% - on north facing slope. At the Tolmachi site with relatively gentle slopes and with similar rates of erosion on the north and south facing slopes, the organic carbon contents in the soils of these slopes were practically the same – 4.3% (Fig. 2 A).

It was also found that the distribution of organic carbon in the soils on the slopes of southern aspects at the Aleksandrovka and Gracheva Loshchina sites is characterized by an increased spatial variability (coefficient of variability 11 and 12%, respectively). At the same time, on the north facing slopes with lower rates of erosion, the variability in the soil organic carbon content was by 1.5–2.0 times lower (5 and 8%, respectively). In Tolmachi site with gentle slopes variability in the soil organic carbon content was low for both slopes (Fig 2 B).

![Graph showing soil organic carbon concentration](image)

**Figure 2.** Soil organic carbon concentration (A) and coefficient of variation of soil organic carbon concentration (B) at key sites Aleksandrovka, Gracheva Loshchina and Tolmachi on slopes of different aspects

234
Development of erosion-accumulation processes lead to forming zones of erosion and zones of accumulation of soil matter, which lead to spatial variability of soil properties. Probably the more extensive erosion-accumulation processes lead to more disintegration of soil cover. That is why variability of soil organic carbon content is more on high eroded south facing slopes against north facing slopes with less rates of erosion and accumulation.

The same erosion and soil characteristics were also studied in arable small river watershed about 0,7 km² in Tula region. Soil sampling was conducted by 10 catenas. Investigations revealed the same trend of spatial distribution of soil organic carbon concentrations in top 25 cm depending on slopes aspect. On south facing slopes SOC content was in average 2,7% on 1 catena, 3,5% on 2 catena, 3,5% on 3 catena and 3,6% on 4 catena; SOC content on east facing slopes was – 3,6% on 5 catena, 3,5% on 6 catena, 3,4% on 7 catena; SOC content on north facing slopes was – 3,9% on 8 catena, 3,8% on 9 catena, 3,8% on 10 catena (Fig 3). So SOC concentrations was lowest in soils of south facing slopes 3,3±0,6; on east facing slopes it was higher 3,5±0,2; on north facing slopes it was highest 3,8±0,1.

![Figure 3. Soil organic carbon concentration (SOC) and coefficient of variation of soil organic carbon concentration in soils on slopes of south (A), east (B) and north (C) exposure on Plavsk key site](image)

Rates of soil erosion within studied watershed on the slopes with approximately the same morphology were higher on slopes with south exposition than on north facing slopes, that confirm investigations presented above. But for all slopes of the watershed trend between rates of soil erosion and exposure of the slopes was not detected, probably because of large differences of lengths, longitudinal and transverse shapes and steepness of the slopes.

But revealed trend between coefficient of variation of SOC and spherical magnetic particles (markers used for studying soil erosion). Coefficient of variation of SOC in soils of south facing slopes was 1,5-2 times more (16±10) then on east and north facing slopes (8±2, 9±5). At the same time coefficient of variation of spherical magnetic particles in soils of south facing slopes was also 1,5 times more (28±4) then on east and north facing slopes (20±6, 21±5). Spatial non-uniformity of spherical magnetic particles distribution evidenced of soil matter movement processes, which likely effected on SOC content in the soils. But at the same time lack of clear trend between rates of soil erosion and SOC concentrations requires further studies.

Conducted researches of erosion and soil properties in the key sites in forest-steppe zone of the Eastern European plain made it possible to conclude:

1. Rates of soil erosion on the same morphology slopes was higher on the slopes of south exposition then on north;
2. Differences between the rates of erosion on the opposite slopes was higher on relatively steep slopes then on gentle slopes;

3. On south facing slopes accumulation of soil matter inside the slopes was much less then on north facing slopes;

4. On relatively steep slopes the organic carbon content in the soils of intensely eroded south facing slopes was considerably lower than in the soils of less eroded north facing slopes. On opposite gentle slopes with similar rates of erosion the organic carbon contents in the soils were practically the same;

5. Variability of soil organic carbon content in the top-soils was higher on the slopes with south exposure against the north on relatively steep slopes. On opposite gentle slopes variability of SOC contents in the soils was practically the same.

ACKNOWLEDGEMENTS

Research was funded by projects: MK-1221.2012.5 and RFBR №10-05-00532.

REFERENCES


