The modification of physical and chemical properties of dark gray forest-steppe soils under the influence of water processes

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Abstract. Potential fertility is determined by many soil properties; mechanical composition, water-physical and chemical properties, including structure, content and qualitative composition of humus, humus layer capacity, total nitrogen and phosphorus content, pH, etc. As a result of long-term agricultural use and erosion processes, these soil properties undergo significant changes. These changes can go in the direction of both improving and cultivating soils - in scientific farming using techniques to increase their fertility, and depleting, "plowing" the soil, up to the destruction or a sharp decrease in their fertility by erosion processes - with extensive farming.

There was always a question before scientists and agrarians: what properties of the soil are the most closely associated with fertility and at the same time are the most dynamic, rapidly changing under the influence of human activity and erosion processes? Researchers have not yet given a completely unambiguous answer to this question.

So, as a result of erosion, the water-physical, chemical and biological properties of soils sharply deteriorate [1]; the power of the humus layer, the content of humus, gross and mobile forms of nitrogen, phosphorus are reduced, the biological activity drops sharply; soils become denser, structureless with low water and air permeability, moisture capacity and high capillarity and evaporation. All this leads to a sharp decrease in crop yields. On eroded gray forest and chernozem soils, the grain yield decreases by 2–5 kg/ha, and on strongly washed soils by 2–3 times. And if you apply innovative tillage, or make fertilizers, you need to look for rational variations that increase the value of fertility and stability [2].

So when solving issues of increasing the efficiency of using mineral fertilizers, it is becoming increasingly important to know not only the general properties of the soil at the moment, but also all the processes occurring in the soil, their dynamics and the relationship with the fertilizers applied. Both sides of the relationship of the specific properties of soils caused by erosion processes, with the features of the use of fertilizers on eroded soils. Changes in the physical, chemical, physico-chemical properties of soils are also determined by the combined action of various factors - the duration of plowing, the position of the soil in the catena row, the exposure of the slope, and the initial structure of the soil profile. [3,4,5]. At present, in Russia, the spatial variability of soil properties is practically not taken into account when assessing the quality of soil cover, during monitoring observations, etc. [6,7,8]

The studies were conducted on gray forest soils of the Kursk region in Kamysli. The sections were laid on a drive-divided, indelible part with a slope of 1–2 ° and on a washed-out slope of 2–5 ° of the...
north-western exposure. The boiling depth at a depth of 130–150 cm, according to the mechanical composition of the arable horizon, the soils are medium- and heavy-loamy, developing on the same mother soil (loesslike loam) and having the same mechanical composition in the lower layers (and initially in the upper layers), the soil profile in as a result of water erosion significantly differentiated by the content of colloidal and clay fractions; the content of the clay fraction in the upper layer of arable soil has changed: in the unwashed - 40.4%, slightly washed - 41.5, medium-washed - 44.0%; accordingly, the content of the colloidal fraction increased from 14.8% in washed away soils (table 1).

Table 1. Mechanical composition, physical properties, structure of eroded dark gray forest-steppe soils.

| Soil           | Horizon | Dept h, cm | Hygroscopic water, % | Specific gravity, g/cm³ | Volumetric weight, g/cm³ | Total porosity, % | Content of particles in size, mm | Number of aggregates in size 0.25-10 mm, % | Dry sieving | Wet sieving |
|----------------|---------|------------|----------------------|--------------------------|--------------------------|------------------|-------------------------------|---------------------------------|-------------|-------------|
| Unwashed       | An 0-25 | 2.91       | 2.64                 | 1.28                     | 51.5                     | 14.8/3           | 40.4/1                        | 66.3               | 55.2        |
|                | A1 A2 30-40 | 2.84       | 2.69                 | 1.35                     | 49.8                     | 29.8             | 50.1                          | 56.7               | 41.1        |
|                | B1 60-70 | 3.64       | 2.71                 | 1.48                     | 44.8                     | 29.5             | 51.5                          | 74.2               | 58.2        |
|                | B2 80-90 | 3.69       | 2.71                 | -                       | 46.2                     | -                | -                             | 45.1               | 57.8        |
| Lightly washed | An 0-25 | 3.84       | 2.67                 | 1.32                     | 50.9                     | 16.8/1           | 41.5/4                        | 56.5               | 49.7        |
|                | A1 A2 25-30 | 2.92       | 2.69                 | 1.37                     | 48.7                     | 20.5             | 42.4                          | 63.3               | 54.0        |
|                | B1 50-60 | 3.15       | 2.71                 | 1.42                     | 48.0                     | 23.6             | 51.0                          | 76.6               | 61.3        |
|                | B2 70-90 | 3.89       | 2.75                 | 1.48                     | 46.2                     | -                | -                             | 54.6               | 58.9        |
| Medium washed  | An 0-25 | 3.13       | 2.77                 | 1.40                     | 49.4                     | 22.3/2           | 44.0/5                        | 48.9               | 33.3        |
|                | B1 35-45 | 4.05       | 2.74                 | 1.42                     | 44.5                     | 35.4             | 56.8                          | 70.7               | 42.5        |
|                | B2 45-60 | 4.36       | 2.77                 | 1.53                     | 44.7                     | 30.9             | 54.0                          | 54.6               | 51.6        |

Note. The content of particles in the size of the numerator in the layer is 0-10, the denominator in the layer 10-25 cm.

In unwashed soils, up to 16.8 and 22.3% - in slightly and medium washed. These changes are associated with tillage in the eroded soils of the illuvial horizon.

Eroded soils are poorly structured: the content of air-dry aggregates in the arable layer was 66% for unwashed soils, 56% for slightly washed, 49% for medium washed ones; respectively water-resistant - 55; 49; 33% Due to the poor structure and heavy mechanical composition, the eroded soils are strongly compacted and crusted, which significantly worsens their water-air regime. In the studies, the field humidity in the 1.5-meter soil layer for all years of study during the spring-summer period on unwashed soils was 2–3% (400–600 m³/ha) higher than on the washed ones. This undoubtedly has a negative effect on the effectiveness of high doses of mineral fertilizers, especially in dry periods and years [9,10,11,12].
The chemical properties of eroded dark gray forest-steppe soils are given in tables (2,3,4). Erosion processes have a significant impact on the gross composition of the soil (table 2); with an increase in the degree of washing, the silica content in the arable layer decreases (from 73 to 70%), and one and a half oxides increase (from 14.47 to 16.6%). Iron oxides are especially indicative in this respect: in unwashed soils, the content of Fe2O3 along the profile is relatively uniform, in washed-out soils it is uneven, with a significant increase (by 2–3%) at a depth of 60–90 cm (horizon B). No changes were observed in the Al2O3 content at these depths. An increase in the Fe2O3/Al2O3 ratio in the horizon B of the washed-out soils can affect the mobility of the introduced phosphorus fertilizers and the efficiency of their use by plants.

The ratio of SiO2: R2O3 in the studied soils ranges from 3.2 to 5.0, and this ratio narrows with an increase in the degree of washability; this is especially noticeable in the arable layer, where in unwashed soils - 5, lightly washed - 4.6; medium washed - 4.2.

The total content of CaO + MgO in the profile of unwashed soils is slightly higher than in washed soils with a clearly observed maximum at a depth of 60–90 cm; in washed away soils, such a maximum at a given depth is not traced, and base accumulation in the arable layer is more clearly visible, apparently due to tillage of the illuvial horizon and partly to biological accumulation (table 2).

**Table 2.** The gross chemical composition of eroded dark gray forest-steppe soils, % on absolutely dry soil (according to E.V. Arinushkina).

| Depth, cm | SiO2 | Al2O3 | Fe2O3 | CaO | MgO | CaO+MgO | P2O5* | R2O3 | SiO2/ R2O3 |
|----------|------|------|-------|-----|-----|---------|------|------|-----------|
| 1. Unwashed soil | | | | | | | | | |
| 0-20 | 73.0 | 10.12 | 4.35 | 4.28 | 1.02 | 5.30 | 0.269 | 14.47 | 5.00 |
| 22-28 | 73.0 | 10.86 | 4.31 | 2.33 | 0.65 | 2.98 | 0.248 | 15.17 | 4.87 |
| 28-38 | 70.2 | 10.70 | 4.67 | 2.16 | 1.86 | 4.02 | 0.210 | 15.37 | 4.60 |
| 38-48 | 71.2 | 11.10 | 4.67 | 1.95 | 1.30 | 3.25 | 0.196 | 15.77 | 4.54 |
| 48-58 | 71.1 | 11.50 | 4.69 | 3.07 | 1.67 | 4.74 | 0.248 | 16.19 | 4.40 |
| 58-68 | 71.7 | 12.30 | 4.95 | 4.56 | 2.33 | 6.89 | 0.228 | 17.25 | 4.15 |
| 68-85 | 69.8 | 13.70 | 4.31 | 3.91 | 2.32 | 6.23 | 0.360 | 18.01 | 3.86 |
| 85-105 | 69.5 | 9.96 | 5.03 | 2.05 | 1.86 | 3.91 | 0.217 | 14.99 | 4.63 |
| >105 | 71.2 | 12.50 | 3.60 | 6.05 | 2.98 | 9.03 | 0.196 | 16.10 | 4.43 |
| 2. Lightly washed soil | | | | | | | | | |
| 0-20 | 72.5 | 11.00 | 4.76 | 2.79 | 2.05 | 4.84 | 0.248 | 15.76 | 4.60 |
| 22-27 | 70.7 | 11.71 | 5.03 | 2.72 | 1.39 | 4.11 | 0.229 | 16.74 | 4.23 |
| 31-41 | 70.9 | 11.61 | 3.87 | 1.86 | 1.30 | 3.16 | 0.210 | 15.48 | 4.56 |
| 41-68 | 70.1 | 12.74 | 6.64 | 2.51 | 1.86 | 4.37 | 0.248 | 19.38 | 3.63 |
| 68-81 | 69.9 | 12.30 | 6.11 | 1.86 | 1.39 | 3.22 | 0.220 | 18.41 | 3.80 |
| >81 | 70.5 | 12.00 | 3.60 | 2.79 | 1.84 | 4.63 | 0.210 | 15.60 | 4.50 |
| 3. Medium washed soil | | | | | | | | | |
| 0-20 | 70.2 | 11.81 | 4.89 | 3.50 | 1.02 | 4.52 | 0.239 | 16.60 | 4.23 |
| 20-27 | 70.7 | 12.56 | 3.87 | 2.05 | 2.05 | 4.10 | 0.238 | 16.43 | 4.28 |
| 27-42 | 69.0 | 13.00 | 3.60 | 2.33 | 1.21 | 4.00 | 0.238 | 16.60 | 4.15 |
| 42-52 | 69.4 | 13.70 | 4.31 | 2.42 | 1.77 | 4.19 | 0.248 | 18.01 | 3.85 |
| 52-90 | 69.5 | 12.80 | 7.20 | 2.79 | 2.78 | 5.57 | 0.247 | 20.02 | 3.47 |
| 90-142 | 70.2 | 13.30 | 4.67 | 2.14 | 2.06 | 4.18 | 0.210 | 17.98 | 4.18 |
| >142 | 69.8 | 12.20 | 4.47 | 4.82 | 2.28 | 6.06 | 0.198 | 16.69 | 4.19 |

Note: Gross phosphorus according to K.E. Ginzburg, G.M., Scheglova, E.A. Wulfius

According to the gross content of phosphoric acid, gray forest soils (including eroded) can be attributed, according to the classification of D.N. Pryanishnikova, to the rich, saturated. They contain a fairly uniform distribution over the profile of 0.2–0.3% P2O5. Significant differences in the content of gross P2O5 depending on the degree of soil erosion are observed only in the arable layer and partially in horizon B: in unwashed soils, phosphoric acid contains more (0.269%) than in lightly washed
(0.248%) and medium-washed soils (0.239%). In unwashed soils, a maximum accumulation of phosphates is observed at a depth of 68–85 cm (which is associated with the manifestation of a podzolic soil formation process); in washed-out soils, a similar increase in the phosphate content in the illuvial horizon is imperceptible. Significant differences are observed in the group composition of phosphates (table 3): in washed–out soils, the phosphate content of 1 g decreases. (in the arable layer from 5.3 mg in unwashed up to 2.5 mg / 100 g in medium-washed) and the content of phosphates III gr. (from 20 to 24 mg in the arable layer); washed –out soils also contain an increased amount of phosphate II gr. compared to unwashed. The data in table 4 show in the same way that in both eroded and non-eroded soils from acid-soluble compounds, phosphorus is mainly represented by group II and III phosphates. The content of phosphates I gr. very low (table 3).

Table 3. The group composition of phosphates of eroded dark gray forest soils (according to Chirikov in the modification of Shkonde).

| Depth, cm | Gross phosphate, mg./100 g of soil | Phosphate group | % of gross phosphorus |
|-----------|-----------------------------------|-----------------|-----------------------|
|           | I | II | III | Total | I | II | III | Total |
| 1. Unwashed soil | | | | | | | | |
| 0-20 | 269 | 5.30 | 7.5 | 20.0 | 32.8 | 2.0 | 2.3 | 7.4 | 11.7 |
| 22-28 | 248 | 2.50 | 9.0 | 22.6 | 34.1 | 1.0 | 3.6 | 9.0 | 13.7 |
| 28-38 | 210 | 1.40 | 8.0 | 21.6 | 31.0 | 0.7 | 3.8 | 10.3 | 14.8 |
| 38-48 | 196 | 1.51 | 12.0 | 22.0 | 35.5 | 0.8 | 6.0 | 11.0 | 17.1 |
| 48-58 | 248 | 1.90 | 9.6 | 20.8 | 36.3 | 0.7 | 5.0 | 8.0 | 14.7 |
| 58-68 | 228 | 3.55 | 12.8 | 21.2 | 37.5 | 1.5 | 5.5 | 9.2 | 16.4 |
| 68-85 | 360 | 3.00 | 7.0 | 28.8 | 38.8 | 0.8 | 1.7 | 8.0 | 17.7 |
| 85-105 | 217 | 1.90 | 8.0 | 22.8 | 32.7 | 0.9 | 3.6 | 10.4 | 15.0 |
| > 105 | 196 | 0.48 | 10.0 | 24.0 | 34.5 | 0.5 | 5.0 | 12.0 | 17.0 |

2. Lightly washed soil | | | | | | | | |
| 0-20 | 248 | 4.35 | 8.4 | 20.4 | 33.1 | 1.7 | 3.3 | 8.0 | 13.3 |
| 22-27 | 229 | 1.50 | 9.0 | 21.5 | 32.0 | 0.6 | 3.9 | 9.3 | 13.9 |
| 31-41 | 210 | 0.48 | 8.4 | 22.0 | 30.9 | 0.2 | 4.0 | 10.5 | 14.7 |
| 41-68 | 248 | 1.20 | 14.8 | 29.4 | 45.4 | 0.5 | 5.9 | 11.8 | 18.3 |
| 68-81 | 220 | 1.85 | 10.2 | 25.2 | 37.2 | 0.8 | 4.6 | 11.4 | 16.9 |
| >81 | 210 | 0.55 | 8.6 | 24.8 | 40.1 | 0.2 | 4.9 | 11.8 | 19.1 |

3. Medium washed soil | | | | | | | | |
| 0-20 | 239 | 2.55 | 10.0 | 24.8 | 37.3 | 1.0 | 2.6 | 10.3 | 13.9 |
| 20-27 | 238 | 1.75 | 9.4 | 24.0 | 35.1 | 0.7 | 3.9 | 10.0 | 14.8 |
| 27-42 | 238 | 1.50 | 12.2 | 25.2 | 38.9 | 0.6 | 5.8 | 10.5 | 16.3 |
| 42-52 | 248 | 1.65 | 12.0 | 28.1 | 41.8 | 0.6 | 4.8 | 11.5 | 16.8 |
| 52-90 | 248 | 1.95 | 12.8 | 29.3 | 44.0 | 0.8 | 5.1 | 11.7 | 17.7 |
| 90-142 | 210 | 1.00 | 8.4 | 27.1 | 36.5 | 0.5 | 4.0 | 12.9 | 17.4 |
| >142 | 197 | 0.48 | 9.6 | 25.6 | 35.7 | 0.2 | 4.8 | 12.8 | 18.1 |

Phosphates of group III make up 7.4% of gross phosphorus in the arable layer of unwashed soil, 8% in lightly washed-out soil, and 10.3% in moderately washed-out soil. All phosphate groups are characterized by their such distribution in the soil profile. There is a slight increase in all phosphate groups in the illuvial horizon at a depth of 40–90 cm. Thus, with an increase in the degree of soil erosion and depth, the availability of phosphorus for plants decreases, and only with the addition of fertilizers can the content of available phosphorus in the washed soil be increased. Studies on the effect of mineral fertilizers on the group composition of phosphates showed a clear decrease in the content of phosphates I gr. in all soils by the time of harvesting in the background without fertilizers and an increase towards the end of the growing season of phosphates of group I and II against the background of NPK.
According to the content of total nitrogen and humus, the studied soils are poorly cultivated. The humus content in the arable layer of these soils varies from 2.7% in unfininished to 2.5% in medium-washed soils. With depth, its content decreases gradually in unwashed soils and rather sharply in washed-out soils. A sufficiently significant penetration of humus into the deeper layers is associated with the participation of both humic and fulvic acids in the humus composition. [13,14] A similar pattern was also found for total nitrogen. The total nitrogen content in the arable layer of unwashed soils reaches 0.21%, in poorly washed soils - 0.18, medium-washed - 0.15%. The soils under study have a close to neutral reaction of the medium; the pH of the salt extract of these soils is 5.9–6.2, not significantly changing with depth and soil erosion. (table 4)

Table 4. Agrochemical properties of eroded dark gray forest-steppe soils.

| № | Soil       | Horizon | Depth, cm | pH | Salt | Hydrolyticity | Amount of absorbed bases | Absorption capacity | Humus, % | Nitrogen total, % | P2O5 | K2O |
|---|------------|---------|-----------|----|------|---------------|-------------------------|-------------------|-----------|------------------|------|-----|
| 1 | Unwashed   | An      | 0-25      | 6.1| 3.96 | 20.1          | 24.0                    | 2.67              | 0.205     | 10.0             | 19.6 |
|   |           | A1      | 25-30     | 6.1| 3.90 | 20.7          | 24.0                    | 2.35              | 0.168     | 9.0              | 19.0 |
|   |           | A1A2    | 30-40     | 6.0| 3.41 | 20.5          | 23.4                    | 2.00              | 0.126     | 8.0              | 19.0 |
|   |           | B1      | 60-70     | 5.9| 3.37 | 20.2          | 23.4                    | 1.00              | 0.070     | 9.8              | 19.8 |
| 2 | Lightly washed | An     | 0-25      | 6.2| 3.84 | 21.0          | 23.8                    | 2.50              | 0.176     | 8.4              | 22.0 |
|   |           | A1A2    | 25-30     | 6.1| 3.23 | 22.0          | 25.2                    | 2.29              | 0.161     | 9.0              | 18.9 |
|   |           | B1      | 50-60     | 6.1| 3.16 | 22.6          | 25.7                    | 0.62              | 0.050     | 11.2             | 18.9 |
| 3 | Medium washed | An    | 0-25      | 6.2| 3.77 | 22.6          | 26.4                    | 2.30              | 0.130     | 7.5              | 19.9 |
|   |           | B1      | 35-45     | 6.0| 3.20 | 23.9          | 27.1                    | 1.35              | 0.120     | 9.4              | 20.0 |
|   |           | B2      | 60-70     | 6.1| 3.06 | 23.5          | 26.5                    | 0.49              | 0.030     | 12.8             | 18.8 |

The hydrolytic acidity of the arable layer of unwashed, lightly, and medium washed soil is 3.96, respectively; 3.84; 3.77 mEq / 100 g of soil. With depth, it gradually decreases down to the parent breed. The absorption capacity of cations in the arable layer of unwashed soil is 24.0 mEq / 100 g of soil, on the medium-washed layer it increases, amounting to 26.4 mEq / 100 g of soil. Against this background, the amount of absorbed bases and the degree of saturation of the bases increase. The content of mobile potassium is high in both unwashed and washed-out soils. The effectiveness of potash fertilizers in experiments is observed only against the background of a complete mineral fertilizer. The data of our studies are largely consistent with the literature data of other researchers [15,16,17,18,19,20].

Under the influence of water erosion, the physical and chemical properties of dark gray forest-steppe soils change significantly: the arable layer of washed – out soils, as a result of the involvement of the illuvial horizon, is enriched in silt and clay fractions, one and a half oxides, absorbed by the bases, and depleted in humus, nitrogen, and soluble phosphorus compounds.

With an increase in the degree of washability, the percentage of poorly soluble and insoluble phosphate groups increases with respect to the total phosphorus content in soils.

In order to increase the efficiency of the use of mineral fertilizers, a differentiated approach is needed when applying them on soils of varying degrees of erosion, taking into account profound changes in the physicochemical properties of the eroded soils.

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