On soil losses from agricultural fields for the periods from 1963 to 1986 and after 1986

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Abstract. Using the radiocesium method the paper presents the results of calculating the rate of erosion processes in agricultural fields of the Orel district of the Orel region for the periods from 1963 to 1986 and from 1986 to the present. It states that soil losses from a field occupied by grain crops have decreased by 3 times after 1986, and from a field occupied by row crops have decreased by 1.5 times.

1. Introduction
In Russia (and, in particular, in the Orel region) for the period from 1986 to 2019, the system of management changed against the background of climate change. In the Orel region, for example, the cultivated areas decreased from 109.7 thousand hectares in 1990 to 77 thousand hectares in 2019. The volume of mineral fertilizers applied per hectare of arable land decreased from 125 kg in 1990 to 15 kg in 2000, with a restoration of volumes in 2016 (they reached 101 kg / ha). In 2019, the volume of applied fertilizers increased to 113 kg per hectare. That is, the previous volumes of applying mineral fertilizers in the Orel region have not been achieved yet. This factor contributed to a decrease in soil productivity indicators. However, the decrease in soil productivity would be even more significant if the rate of erosion processes on the plowed slopes had not decreased. An analysis of the depth distribution of cesium-137 of Chernobyl origin can show what changes in the intensity of erosion processes occurred in the fields of the Orel region.

The warming of the winter period contributed to the decrease in the intensity of soil losses. According to Novosilskaya ZAGLOS, for the period from 1991 to 2019, the depth of soil freezing on arable land in winter exceeded 25 cm only in 7 years out of 29. The tightness of the statistical relationship between the runoff from the fall-plowed land and water reserves in the snow sharply decreased. If in the period 1959-1964 the coefficient of correlation between runoff from the fall-plowed land and water reserves in the snow sharply decreased. If in the period 1959-1964 the coefficient of correlation between runoff from the fall-plowed land and water reserves in the snow reached 0.95, then in 1964-1986 it dropped to 0.39, and in 1987-1919 – to 0.30. These data show that the year 1986 practically coincided with the beginning of a period of a sharp decrease in the intensity of erosion processes on arable slopes. In the soil, the 1986 layer is now “marked” with high cesium-137 values. This is explained by the fact that cesium-137 is embedded in clay minerals of the montmorillonite group and moves along with the soil. Therefore,
when the upper, fertile soil layer is washed away, arable tools capture the lower subsurface layer, which is uncontaminated with radiocaesium, and the specific activity of the soil in the integral soil sample decreases. Cesium-137, as studies have shown [2-10], is a fairly correct mark, fixing the depth of the arable soil layer in 1986.

As our studies have shown, on the experimental site (on the slope of the northern exposure), mobile phosphorus, in contrast to cesium-137, marks the depth of plowing until 1986. Phosphorus, as an indicator of the content of mineral fertilizers, which were introduced in sufficient quantities during the Soviet period, has remained in arable layer to date. Thus, “working” with two marks, we will be able to assess more correctly the degree of soil losses during the post-Chernobyl period in fields with different crops.

**The aim of the work** is to identify how soil losses have changed over two periods: 1963-1986 and after 1986. To establish whether cesium-137 of Chernobyl origin, which identifies soils of different degrees of soil losses, can correlate with the amount of mobile phosphorus in the arable layer, the lower boundary of which identifies the depth of the “pre-Chernobyl” arable horizon.

### 2. Materials and methods

Lately the radiocaesium method has become widespread. The application of this method in agricultural fields is complicated by the fact that it is not always possible to accurately establish the so-called reference (background) value of cesium-137 inventory in the arable layer. Comparison of the radiocaesium inventory at any point in the field with its inventory at the reference site allows determining soil losses at the studied point [7-10]. The proposed method of statistical estimation of the reference inventory based on data from several points [7] does not take into account the structure of the soil cover on the watershed surfaces located in the periglacial zone of the Russian Plain. The microrelief of the watershed surfaces in this zone is represented by block elevations and interblock depressions of paleocryogenic origin [1]. The authors of this article propose to determine the value of the radiocesium inventory at the reference site from the measurement data within the block increases. On block elevations located on a relatively flat watershed surface, soil losses are minimal [1]. The second problem that arises when determining the reference inventory is the problem of determining the depth of soil sampling correctly. The global fallout of radiocaesium from the atmosphere in the pre-Chernobyl period in the study area was small. According to the control points of the Orlovsky Center for Chemicalization and Agricultural Radiology, the maximum specific activity of cesium-137 in 1972 reached 10 – 15 Bq / kg. This is in relation to the Chernobyl values of the activity of cesium-137 no more than 10%. Consequently, it can be assumed that almost the entire inventory of radiocaesium in the arable layer is due to the Chernobyl fallout.

Experimental studies were carried out on three agricultural fields located in the Sukhaya Orlitsa river basin in the Orel district of the Orel region. Layer-by-layer sampling of soil by depth on three reference sites of three fields, gamma-spectrometric and agrochemical analyzes of soil samples allowed the authors of this article to make the following recommendations.

In addition to taking soil samples at each reference site, the authors propose to take soil samples layer by layer in depth in dry channels of depressions – “receiving” overburdens coming from the studied agricultural fields. The radionuclides buried in depressions (located on natural slopes) carry information about the fallout of 1986, which was not affected by agricultural machinery and the removal of cesium-137 with the crop. As a result, it becomes possible to reasonably assign a reference inventory of radiocaesium for each studied field.

In the course of the research, the authors faced the problem of interpreting the features of the depth distribution of such an indicator of soil productivity as mobile phosphorus. It is known that gray forest soils, into which large doses of phosphorus fertilizers were systematically applied, contain more than 15 mg \( P_2O_5 \) per 100 g of soil in the arable horizons. Consequently, on old-arable gray forest soils, where during the Soviet era a lot of phosphorus fertilizers were applied, the lower limit of high values of \( P_2O_5 \), as a rule, “marks” the lower limit of the arable horizon until 1986. In case that the depth of the maximum value of \( P_2O_5 \) coincides with the depth of the maximum value of cesium-137, it can be said with a high degree of confidence that the radiocaesium inventory up to this depth corresponds to
the background value of cesium-137 for a given agricultural field. In the fields for which the history of their land use has not been preserved, the results of such an analysis also help to reconstruct the crops that were sown in these fields in the pre-Chernobyl period. The depth of the maximum value of mobile phosphorus that is more than 25 cm may indicate that the field in some years was occupied by row crops (for example, potatoes).

3. Results
Figure 1 shows a fragment of a satellite image with three fields. On field No. 3 (it is located on the slope of the southern exposure), the reference value, established from the data of layer-by-layer sampling of soil in depth in the arable layer of 0-25 cm, is equal to 172.3 Bq / kg. On field No. 2 (on the watershed surface of the northern exposure slope), the reference value of cesium-137 is 180 Bq / kg.

Figure 1. Fields No. 1, 2, 3. 170.1 – cesium-137, Bq / kg. Point 5 is a place of sampling of soil in the depression (near Field No. 1); points 4, 6 – in the balka (near Field No. 3)

On Field No. 1 (near the village of Kireevka), the reference value of the specific activity of cesium-137 is 133.8 Bq / kg. It can be seen that Field No. 1 is sharply distinguished by the small value of the reference value of cesium-137. To clarify the cause of this anomaly, soil cuts were made in unplowed areas. Point No. 5 is in the depression (below Field No. 1), Points No. 4 and No. 6 are in the balka (below Field No. 3). The depression and the balka were as “traps”, “receiving” the overburdens washed away from the analyzed fields (Figure 1).

Figure 2 shows the diagrams of the depth distribution of cesium-137 and mobile phosphorus at a point located on the watershed surface of Field No. 1 (on the reference site). It can be seen from the diagrams that the depth of the arable horizon, recorded simultaneously by the maximum values of cesium-137 and the maximum values of mobile phosphorus is 32-34 cm. Deeper than 34 cm, there is a sharp decrease in the specific activity of cesium-137 (from 143 – 163 Bq / kg to 43 Bq / kg) and mobile phosphorus (from 19.8-22 mg / 100 g to 13-17 mg / 100 g). Deep plowing on Field No. 1 may indicate that row crops (most likely potatoes) were planted on this field both before 1986 and after 1986.
Figure 2. Distribution of cesium-137 and mobile phosphorus in depth on the reference site of Field No. 1.

Figure 3 shows a diagram of the distribution of cesium-137 at Point No 5, which “receives” overburdens from Field No. 1 (samples were taken in 2020). The diagram shows that cesium-137 of 1986 is equal to 160-168 Bq / kg. The average value of the specific activity in the layer up to the peak at a depth of 32-34 cm was 133.8 Bq / kg. Comparison of the diagram at Point No. 5 (Figure 3) with the diagrams at Points No. 4 and 6 (figures 3 and 4) allows asserting that the local fallout on Field No. 1 in 1986 was less than in Field No. 3 (163 Bq / kg against , respectively, 237 and 336.9 Bq / kg).

Figure 3. Diagrams of the depth distribution of cesium-137 in the depression receiving overburdens from Field No. 1 (Point No. 5) and in the balka receiving overburdens from Field No. 3 (Point No. 4).

Figure 4. Diagram of the depth distribution of cesium-137 in the balka receiving overburdens from Field No. 3 which come through a deep depression with a watershed area of more than 50,000 m² (Point No. 6).
4. Discussion
From the analysis of these diagrams in Figure 3, the following becomes clear. The reference value for Field No. 1 must be set specifically for this field, since in 1986 the fallout of cesium-137 in this area was less than in Field No. 3. The soil losses from Field No. 3, occupied by grain crops, was not so great during the post-Chernobyl period (12 cm for 30 years, that is, 0.4 cm per year) as from Field No. 1 (32-34 cm for 34 years, that is, 0.97 cm per year). Field No. 1, probably before and after 1986, was occupied by row crops. Fields differ in exposure and slope (slopes of the surface of Field No. 3 are 1º - 4º; slopes of Field No. 1 are no more than 1º). The fields also differ in the degree of ruggedness by erosional furrows, as well as in the depth of plowing. The plowing depth on Field No. 3 is no more than 25 cm. On Field No. 1 is up to 34 cm. Field No. 1 is located on a watershed surface, practically not covered with depressions. Field No. 1 has many valleys of different sizes. What kind of soil washout goes through the depressions? To answer this question, we sampled the soil layer by layer (every 2 cm) in the balka below the depression which fell in it, and carried the soil from Field No. 3. The watershed area of the depression is more than 50,000 m² (sampling Point No. 6 in Figure 1). Comparison of the volumes of overburden delivery along this depression (to Point No. 6) with the delivery of overburden from Field No. 1 (to point No. 5) showed the following. It turned out that in a depression with a watershed area of more than 50,000 m² (on the slope of the southern exposure) to Point No. 6 (Figure 4), the intensity of overburden delivery (or the intensity of soil losses) during the post-Chernobyl period was 0.87 cm / year. The same values during this period reached the intensity of soil losses from Field No. 1 occupied by row crops (at Point No. 5, the rate of overburden delivery per year was 0.97 cm per year). Thus, we found that during the post-Chernobyl period, the soil losses from the field occupied by row crops were comparable to the soil losses of the soil along large depressions on the southern slope. The diagram constructed according to the data of the layer-by-layer analysis of the distribution of cesium-137 in depth at Point No. 5 (Figure 3) can also help to estimate the intensity of soil losses for the period from 1963 to 1986. The mark of 1963 is the value of cesium-137, equal to 17.8 Bq / kg at a depth of 68-70 cm. If we assume that at Point No. 5, the depth of the second maximum of 68-70 cm fixes the global fallout of 1963 [4-6], then it can be stated that during the period from 1963 to 1986 (23 years) 34 – 36 cm of overburden was washed away from Field No. 1. The rate of overburden delivery from 1963 to 1986 was about 1.57 cm per year. In the post-Chernobyl period, it decreased to almost 1 cm per year (that is, it decreased by 1.5 times).

The 1963 mark at Point No. 4 is the value of cesium-137 of 11.2 Bq / kg at a depth of 48-50 cm (Figure 3). Consequently, about the same amount of overburdens (38 cm in 23 years) was delivered to the balka (Point No. 4) from Field No. 3 (located on the slope of the southern exposure) for 23 years (from 1963 to 1986) as from Field No. 1. For the period from 1986 to 2020, 12 cm were delivered. That is, the intensity of soil losses during the post-Chernobyl period was 0.4 cm per year. It is obvious that the intensity of soil losses in the post-Chernobyl period decreased by 3 times. Thus, we have established that the intensity of erosion processes in the studied fields decreased after 1986 by 1.5-3 times.

5. Conclusion
It has been established that the intensity of washout of gray forest soil on agricultural fields in the upper Oka basin for the period from 1986 to the present has decreased by 1.5 – 3 times compared with the period before 1986. The greatest decrease in the intensity of soil losses in the post-Chernobyl period (by 3 times) occurred in the fields occupied with grain crops. In the fields periodically occupied with row crops, the intensity of soil losses decreased by 1.5 times.

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