Assessing the Impact of Industrial Poultry Waste on the Soil Cover

L E Tuchkova¹, I A Verkhovets¹, I M Tikhoykina², E S Chuvasheva¹
¹Orel State University, the Orel Region, Komsomolskaya Street, 95, 302026, Orel, Russia
²Orel State University of Economy and Trade, the Orel Region, Oktyabrskaya Street, 12, 302028, Orel, Russia

E-mail: lutuchka@ya.ru

Abstract. The paper describes the impact of industrial poultry waste on the soil pollution degree. Analysis of the results of studying the sanitary-biological indicators of the soil cover for 2017 and 2019 has shown an increase in the pollution with coliform bacteria. High focal pollution of soils with nitrate nitrogen has been detected, which has led to the formation of patches in the soil cover. In 2017, a significant excess of the MPC by all chemical and toxicological indicators of the heavy metal mobility was detected, and 2019 studies showed an excess of the MPC by only copper and zinc. The studied plot belongs to agricultural land of the high-risk category; it is subject to biological pollution and contaminated with heavy metals.

1. Introduction
Industrial poultry farming is an integral and highly specialized part of the agro-industrial complex. The great advantages of this industry are independence from natural and climatic conditions, high productivity, the possibility of using waste as secondary raw materials, high payback, and consistently high demand for poultry products. However, like any production facility, industrial poultry farming has a huge impact on the environment and soil cover, particularly, as an object of heavy metal contamination and a source of biological and bacteriological pollution [3, 10, 12].

Along with other types of waste such as industrial and solid municipal ones, poultry waste has a huge impact on the soil cover degradation [1, 2, 19]. A large part of heavy metals contained in waste occurs in the soil in the composition of various compounds [9], including mobile ones, which leads to the migration of heavy metals and their accumulation in environments in quantities hazardous to living organisms [7].

In this regard, the research objective was to assess the degree of the industrial poultry waste impact on the state of gray forest soil.

The research tasks included:
1. Assessing the degree and intensity of soil pollution with industrial poultry waste.
2. Ecological and economic assessing soils polluted with industrial poultry waste.

The research was performed in 2017-2019, based on the data of the Oryol Branch of the FSBI Central Scientific and Methodological Veterinary Laboratory.
The impact of industrial poultry waste on the soil cover was assessed by the sanitary and biological indicators, the content of nitrate nitrogen, and the chemical and toxicological indicators of the heavy metal mobility.

Gray forest soils of farmland were polluted with industrial poultry waste of AIC Orlovskaya Niva JSC. Land plot with cadastral number 57:06:0050102:457 is located in the Oryol Region, Uritsky District, Lunacharsky rural settlement.

The sanitary characteristics of the populated area soils are based on laboratory sanitary-chemical, sanitary-bacteriological, sanitary-helminthological, and sanitary-entomological indicators.

2. Results and discussion
The data given indicate that the land plot has no area meeting the rate for the CGB index (Escherichia coli group bacteria); herewith, it should be noted that no helminth eggs and larvae have not been found (Table 1).

| Sample No. | 2017          | Year of research | 2019       |
|------------|---------------|------------------|------------|
| 1.         | 100-1,000     | 1-10             | 1-10       |
| 2.         | 10-100        | ≥1,000           | 10-100     |
| 3.         | 100-1,000     | ≥1,000           | 1-10       |
| 4.         | 10-100        |                 | 1-10       |
| 5.         | 100-1,000     | 10-100           |            |
| 6.         | 10-100        | ≥1,000           |            |
| 7.         | 100-1,000     | 10-100           |            |
| 8.         | 10-100        | 1-10             |            |
| 9.         | 100-1,000     | 100-1,000        |            |
| 10.        | 10-100        |                  | 100-1,000  |
| 11.        | 10-100        | 1-10             |            |

In 2017, a 10-time excess of the CGB index was observed in 54.5% of samples, i.e. Nos. 2, 4, 6, 8, and 10, and a 100-time excess in samples Nos. 1, 3, 5, 7, and 9, at a rate of 1-10. In 2019, the pollution of 36.4% of the land plot did not exceed the rate, and 10- and 100-time excess was detected in 18.2 and 43.4% of the area. Thus, the coliform pollution area was reduced, and the concentration increased.

According to the bacteriological analysis results, the sanitary-bacteriological indicators of the soil samples under study 10 and 100 times exceed the level of coliform organisms (CGB) permissible for clean soil, which confirms the soil assessment as contaminated one and the classification of the studied land plot as high-risk farmland. The coliphage concentration of 10 CFU per 1 g or more indicates the soil infection with enterovirus and the possible pollution with salmonella. The research has proven the absence of helminth eggs and larvae.

Thus, increased biological pollution leads to deteriorating the self-cleaning capacity of the soil, increasing its toxicity and infectious and invasive potential, and a negative impact on the environment [8, 18].

“The nitrogen cycle determined by its bacterial fixation and further transformation is closely related to another powerful cycle of this element. Large masses of nitrate and ammonium nitrogen are captured from the pedosphere into the biological cycle occurring due to the activity of photosynthetic plants and microorganisms that destroy plant residues. The decomposition of organic matter under anaerobic conditions (ammonification) leads to the accumulation of ammonium ions in the soil. When organic
matter decomposes under aerobic conditions (nitrification), nitrates accumulate in the soil” [11] (Table 2).

Table 2. Mass Fraction of Nitrate Nitrogen, mg/kg.

| Year | Sample | MPC |
|------|--------|-----|
| 2017 | 54.1   | 130.0 |
| 2019 | 293.0  | 220.72 |

The 2017 research results confirm the uneven distribution of nitrate nitrogen in the soil cover under study. The content of nitrate nitrogen in polluted soil exceeds the MPC by 1.2 and 4.3 times. This determines the accumulation of nitrates in the soil and, consequently, crop products. Excessive content of nitrate nitrogen leads to soil acidification, compaction, and loss of the structural state and, consequently, excessive accumulation of manganese and aluminum [4,5].

In 2019, the analysis of the nitrate nitrogen content in the investigated soil samples has shown an excess in the MPC by the concentration factor in samples 1 and 2 by 1.5 and 2.7 times, respectively. In other samples, the nitrate nitrogen content did not exceed the MPC and was within 55.8-85.5 mg/kg. Consequently, it allows confirming the focal pollution of the soil with nitrates and the formation of patches with a high level of nitrate nitrogen pollution in the soil cover. The data in Table 3 confirm the impact of industrial poultry farming on the pollution of the soil cover with heavy metals; thus, in all the analyzed soil samples, a significant amount of accumulated mobile forms of heavy metals of interest has been detected: copper (Cu), cobalt (Co), zinc (Zn), lead (Pb), nickel (Ni), manganese (Mn), and arsenic (As).

Table 3. The Content, Concentration Factor, and Total Accumulation of Mobile Forms of Heavy Metals in the Humus Layer of Gray Forest Soil, 2017.

| Sample No. | Co  | Mn   | Ni   | Cu  | As  | Pb   | Zn  | Zc  |
|------------|-----|------|------|-----|-----|------|-----|-----|
| 1          | 0.49| 527.04 | 1.49 | 34.53 | 44.7 | 9.34 | 218.24 |
| Kc MPC     | 0.10| 6.59  | 0.37 | 11.51 | 22.35 | 1.56  | 9.49 | 47.5 |
| Kc BG      | 1.81| 44.10 | 1.22 | 101.56 | 12.10 | 3.98  | 41.97 | 200.72 |
| 2          | 0.51| 131.8 | 0.93 | 4.94  | 30.15 | 8.78  | 10.64  |
| Kc MPC     | 0.10| 1.65  | 0.23 | 1.65  | 15.08 | 1.46  | 0.46 | 19.6 |
| Kc BG      | 1.89| 11.03 | 0.76 | 14.53 | 8.15  | 3.72  | 2.05 | 36.37 |
| 3          | 0.61| 131.80 | 1.08 | 8.6   | 20.48 | 7.06 | 30.34 |
| Kc MPC     | 0.12| 1.65  | 0.27 | 2.87  | 10.24 | 1.18  | 1.32 | 13.26 |
| Kc BG      | 2.26| 11.03 | 0.89 | 25.29 | 5.54  | 2.99  | 5.84 | 47.95 |
| 4          | 0.89| 178.94 | 1.03 | 3.19  | 20.48 | 4.99 | 16.48  |
| Kc MPC     | 0.18| 2.24  | 0.26 | 1.06  | 10.24 | 0.83  | 0.72 | 11.54 |
| Kc BG      | 3.30| 14.97 | 0.84 | 9.38  | 5.54  | 2.11  | 3.17 | 33.47 |
| 5          | 0.42| 131.80 | 0.97 | 4.57  | 24.12 | 4.16 | 18.97  |
| Kc MPC     | 0.08| 1.65  | 0.24 | 1.52  | 16.06 | 0.69  | 0.82 | 17.23 |
| Kc BG      | 1.56| 11.03 | 0.80 | 13.44 | 6.52  | 1.76  | 3.65 | 32.96 |
| 6          | 0.49| 184.31 | 1.49 | 11.66 | 23.10 | 8.26 | 30.25  |
| Kc MPC     | 0.10| 2.30  | 0.30 | 3.89  | 11.55 | 1.38 | 1.32 | 16.44 |
| Kc BG      | 1.81| 15.42 | 1.22 | 34.29 | 6.24  | 3.50 | 5.82 | 64.11 |
| 7          | 0.33| 171.47 | 0.20 | 23.75 | 21.56 | 8.18 | 223.64 |
| Kc MPC     | 0.07| 2.14  | 0.05 | 7.92  | 10.78 | 1.36 | 9.72 |
| Kc BG      | 1.22| 14.34 | 0.16 | 69.85 | 5.83  | 3.47 | 43.0 | 131.71 |
| 8          | 0.71| 195.38 | 2.09 | 20.23 | 24.29 | 7.30 | 37.63  |
The quantitative accumulation of these heavy metals in the polluted soils as compared to their content in the reference (background) soil showed an excess of 6.5-25.7 times (9 soil samples) and 29-102 times (5 soil samples) by copper, 11-44.1 times (13 soil samples) by manganese, 2-4 times (10 soil samples) by lead, and 2-7.6 times (11 soil samples) by zinc, and in two soil samples, the excess of mobile copper reached 42-43 times. An excess in the amount of mobile cobalt was 1.5-3.6 times. The change in the amount of arsenic in polluted soils, the content of which was 5.5-12.1 times higher than in the reference sample, was especially noteworthy.

The determined intensity of the quantitative accumulation of heavy metals in soils due to the violated organic waste utilization technology in the poultry farming causes high soil pollution with the total accumulation factor of these metals reaching 36-64 and a significant pollution level with the total metal accumulation factor of up to 200.

The content of metals such as copper, lead, zinc, manganese, and arsenic in samples taken from disturbed soils exceeded the maximum permissible concentration by each metal; thus, the excess of MPC by copper, zinc, lead, manganese, and arsenic reached 1.5-11.5, 1.5-9.7, 1.5, 2.2-6.6, and 10.1-22.3 times, respectively.

The specifics of assessing the danger of polluting the studied area is the impossibility of using the typical estimation indicator - the Saet index of technogenic concentration calculated as the sum of the ratios of the actual to the background concentrations of the pollutants [6]. This is associated with the too-low local background concentrations of metals of interest, according to the data of soil sample No. 15, due to which the coefficient can be very high. In this regard, the data in Table 3 confirm the assumption that the total pollution factor reaches 47.5, 5.41, and 20.19 in soil samples Nos. 1, 9, and 8, respectively. For soil samples Nos. 2, 3, 4, 5, and 6, the total pollution factor is within 11.54-19.6, and only for soil samples Nos. 10-14 taken from the disturbed area, the factor value was within 1.64-7.28. The total pollution factor values obtained for the soil contaminated with heavy metals as compared to the maximum permissible concentrations characterize high pollution level for sample No. 1, average pollution level for soil samples Nos. 2, 5, 6, 8, and 9, and low pollution level for only soil samples Nos. 3 and 4, and for soil samples Nos. 10, 11, 13, and 14, the factor values characterize minimum pollution level. When considering the impact of waste generated by poultry farming on the composition and

| \( K_{\text{MPC}} \) | \( K_{\text{BG}} \) | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|----------------|--------------------|---|----|----|----|----|----|----|
| 0.14 | 2.44 | 0.52 | 6.74 | 12.15 | 1.22 | 1.64 | 20.19 |
| 2.63 | 16.35 | 1.71 | 59.5 | 6.56 | 3.09 | 7.24 | 91.08 |
| 0.42 | 178.94 | 1.01 | 8.75 | - | 8.93 | 39.24 |
| 0.08 | 2.30 | 0.25 | 2.91 | - | 1.49 | 1.71 | 5.41 |
| 1.56 | 28.93 | 0.83 | 25.73 | - | 3.78 | 7.55 | 63.55 |
| 0.49 | 131.80 | 1.18 | 9.83 | - | 8.15 | 28.11 |
| 0.09 | 1.65 | 0.29 | 3.28 | - | 1.36 | 1.22 | 4.51 |
| 1.81 | 11.03 | 0.97 | 28.91 | - | 3.45 | 5.41 | 46.61 |
| 0.61 | 112.87 | 1.18 | 3.70 | - | 2.15 | 15.31 |
| 0.12 | 1.41 | 0.29 | 1.23 | - | 0.34 | 0.67 | 1.64 |
| 2.26 | 9.45 | 0.97 | 10.88 | - | 0.91 | 2.94 | 22.53 |
| 0.80 | 131.80 | 1.41 | 2.25 | - | 2.47 | 6.77 |
| 0.16 | 1.65 | 0.35 | 0.75 | - | 0.41 | 0.29 | - |
| 2.96 | 11.03 | 1.16 | 6.43 | - | 1.05 | 1.3 | 18.98 |
| 0.61 | 178.94 | 1.26 | 4.99 | - | 2.80 | 21.32 |
| 0.12 | 2.24 | 0.32 | 1.66 | - | 0.47 | 0.93 | 2.90 |
| 2.26 | 14.97 | 1.03 | 14.68 | - | 1.19 | 4.10 | 33.23 |
| 0.61 | 527.04 | 1.07 | 4.11 | - | 7.10 | 26.3 |
| 0.12 | 6.59 | 0.27 | 1.37 | - | 1.18 | 1.14 | 7.28 |
| 2.26 | 44.10 | 0.88 | 12.08 | - | 3.01 | 5.06 | 62.51 |
| 0.27 | 11.95 | 1.22 | 0.34 | 3.70 | - | 2.36 | 5.20 |
accumulation of heavy metals, the lack of significant infusion of technogenic elements as compared to the MPC can only be indicated for soil samples Nos. 7 and 12.

Herewith, when disregarding the maximum permissible concentrations, a significant increase in the concentrations of some elements, mainly copper, zinc, and lead can be indicated, as compared to the minimum values detected in the investigated area, which have been conditionally adopted as the local background. When operating with background values, then a significant accumulation of the metals of interest is detected in the area under study, which allows speaking of the soil as a kind of protective screen that prevents both vertical and horizontal migration of heavy metals [17]. Thus, in the upper humus layer of gray forest soils, the total heavy metal accumulation factor for samples Nos. 1 and 7 varies within 131.71-200.72, which characterizes the maximum pollution level, and for soil samples Nos. 6, 8, and 9, the total accumulation factor is within 64.11-91.08 and characterizes very high pollution level. For the humus horizons of soil samples No. 2, 3, 4, 5, 10, 13, and 14, the total accumulation factor varies within 32.96 to 62.51 and characterizes the high pollution level. For samples Nos. 11 and 12, the total pollution factor is within 18.98-22.53, which attributes the soil to the category of average pollution level.

It should be noted that the high level of heavy metals and the formation of technogenic geochemical anomalies Mn>Zn>As>Cu>Pb>Ni>Co in soils disturbed by the accumulation of heavy metals under the impact of production waste, and geochemical anomalies formed in natural background gray forest soils not directly affected by the main pollution sources in the area under study Mn>Zn>As>Pb>Ni>Cu>Co (background) may cause the total effect of the metal mix in the soil environment or create conditions for the greatest impact of the most toxic metal, which may lead to negative consequences [15, 16].

When considering the impact of local heavy metal sources such as industrial poultry farming on their accumulation in the plowing horizons of gray forest soils, a significant infusion of technogenic elements into soils can be stated (Table 4).

| Sample No. | Copper Value | Nickel Value | Lead Value | Zinc Value | Zn MP C Value |
|------------|--------------|--------------|------------|------------|---------------|
| 1.         | 0.2          | 0.32         | 0.60       | 0.87       | 0.73          | 1.04          | 5.95 | 2.00 |
| 2.         | 1.44         | 2.29         | 0.54       | 0.78       | 0.77          | 1.10          | 15.76 | 5.29 |
| 3.         | **11.84**    | **3.95**     | 1.40       | 2.03       | 1.22          | 1.74          | **58.24** | 2.53 |
| 4.         | 0.2          | 0.32         | 0.66       | 0.96       | 0.75          | 1.07          | 3.13  | 1.05 |
| 5.         | 2.05         | 3.25         | 0.67       | 0.97       | 0.98          | 1.40          | **29.82** | 1.30 |
| 6.         | 0.2          | 0.32         | 0.77       | 1.12       | 1.08          | 1.54          | 3.88  | 1.30 |
| 7.         | 0.51         | 0.81         | 0.59       | 0.86       | 0.92          | 1.31          | 10.82 | 3.63 |
| 8.         | 1.39         | 2.21         | 0.85       | 1.23       | 0.80          | 1.14          | 12.40 | 4.16 |
| 9.         | **5.22**     | **1.74**     | 0.80       | 1.16       | 0.67          | 0.96          | **41.25** | 1.79 |
| 10.        | 0.71         | 1.13         | 0.69       | 1.00       | 0.97          | 1.39          | 8.01  | 2.69 |
| 11.        | 0.63         | 1.00         | 0.84       | 1.22       | 0.78          | 1.11          | 6.56  | 2.20 |
| 12.        | 2.19         | 3.48         | 0.96       | 1.39       | 0.65          | 0.93          | 9.40  | 3.15 |
| 13.        | 2.39         | 3.79         | 0.71       | 1.03       | 0.83          | 1.19          | 12.16 | 4.08 |
| 14.        | 0.95         | 1.51         | 0.80       | 1.16       | 0.79          | 1.13          | 3.81  | 1.28 |
| 15.        | **4.76**     | **1.59**     | 0.75       | 1.09       | 0.72          | 1.03          | **27.70** | 1.20 |
| 16.        | 2.64         | 4.19         | 0.84       | 1.22       | 0.77          | 1.10          | 11.05 | 3.71 |
| 17.        | **8.73**     | **2.91**     | 1.20       | 1.74       | 0.73          | 1.04          | **55.78** | 2.43 |
| 18.        | 1.41         | 2.24         | 0.69       | 1.00       | 0.81          | 1.16          | 4.94  | 1.66 |
| 19.        | 1.26         | 2.00         | 0.84       | 1.22       | 0.58          | 0.83          | 3.90  | 1.31 |
| 20.        | **7.86**     | **2.62**     | 0.83       | 1.20       | 1.01          | 1.44          | **35.31** | 1.54 |
| 21.        | 2.29         | 3.63         | 0.68       | 0.99       | 0.75          | 1.07          | 12.63 | 4.24 |
| 22.        | 2.42         | 3.84         | 0.67       | 0.97       | 0.75          | 1.07          | 0.75  | 0.25 |
| 23.        | 1.59         | 2.52         | 0.76       | 1.10       | 0.92          | 1.31          | 13.39 | 4.49 |
The analysis of accumulating heavy metals such as copper, nickel, lead, and zinc caused by industrial poultry farming has shown an excess of MPC for mobile forms of copper and zinc in 9 of 30 soil samples being analyzed, in which the degree of an excess of MPC reaches 1.09-3.95 for copper and 1.2-2.53 for zinc. If compare the amounts of all mobile metals of interest with their amounts in the reference sample, then an excess of the level of heavy metals over the reference amount can be determined as follows: 0.32 - 4.19 by copper, 0.78-2.03 by nickel, 0.8-1.74 by lead, and 0.25-5.67 by zinc. Based on the MPC values and as compared to the background ones, the total pollution factor is acceptable. Herewith, the total pollution indicator was within 1.19-5.48 at the background value within 0.4-7.63. Thus, the 2019 study has established an excess of MPC by copper and zinc.

3. Conclusions

The data obtained give ground to attribute the soil cover of the farmland to a high pollution level, which causes a sharp deterioration of the self-cleaning soil capacity, an increased transfer of the metals of interest from the plowing soil layer through the root system of plants, and their accumulation in the soil and crops in quantities exceeding the MPC, as well as the accumulation of heavy metals in human and animal organisms.

The high concentrations of mobile forms of arsenic, copper, zinc, and lead create the risk of their negative impact on the warm-blooded animal and human organisms, causing functional impairments. The accumulation of heavy metals reduces the bio productivity of lands and simultaneously inhibits the enzymatic and microbiological activity of soils, which leads to a reduced accumulation of humus and the deteriorated complex- and structure-forming capacity and the bioactivity of the soil solution, which reduces the resistance of soils to overfatigue, gleying, and pollution. The accumulation of heavy metals in the soil leads to an increase in their mobility, penetration into deeper soil layers, the pollution of vegetation, the suppression of biota, and the increased content of heavy metals in groundwater.

The calculation of economic damage from changes in fertility due to an anthropogenic impact on the soil cover expressed in pollution with industrial poultry waste showed the damage to the soil cover with an area of 22,008 m² in 2017 and amounted to RUB 70,425 thousand. In 2019, the area of disturbed lands increased and amounted to 23,442 m², and the damage decreased 1.88 times and amounted to RUB 37,507 thousand.

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