Stocks of organic substance in post-agrogenic lands in Leningrad region

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Abstract. We have analysed factors affecting the formation of organic matter stocks in sod-podzolic soils and post-agrogenic lands in the south-western part of the Leningrad region. There are many factors influencing the process of humus formation, which does not allow to reliably simulate the process of transformation of organic residues and the accumulation of humus in areas previously used for agricultural production. There is a connection in the differences in the specific density of the soil and the unequal content of humus in the genetic horizons of fallow soil compared to the arable layer of the field, where these horizons are mixed into a homogeneous mass. The data obtained show a high correlation between the humus content in the former arable horizon of soil with a clay fraction and pHKCI. At different successional stages of accumulation of organic matter in post-agrogenic lands is not the same, as the formation of different species composition of vegetation makes adjustments to this process. When determining humus stock in post-agrogenic lands, an error can reach to 30%. The main reason is the differences in the specific density of the soil and the unequal content of humus in the genetic horizons of fallow soil compared to the arable layer of the field, where these horizons are mixed into a homogeneous mass. The conclusion was made about different methods of soil sampling from arable lands and from post-agrogenic lands.

1. Introduction

Land use has a major impact on soil carbon and nitrogen dynamics. Dominant paradigms argue that arable land cultivation results in long-term and large losses of soil carbon compared to fallow fields and forests. It is assumed that tillage, mainly the conversion of pastures to arable land, leads to significant losses of organic carbon. Agricultural land after the cessation of their active cultivation is resumed by natural vegetation, and the soil again accumulates organic carbon. [1, p. 31].

This accumulation process reverses the effects responsible for the loss of organic carbon in the soil from the moment it is deprived of perennial vegetation. There are significant differences in the time and rate of carbon accumulation in the soil, due to the productivity of regenerating vegetation, physical and biological conditions in the soil and the past history of soil enrichment with organic matter and physical effects on it. The maximum accumulation of organic matter during the initial stage of growth perennial vegetation, although significant, is usually much less than in the previous history of organic carbon entering the soil [1]. Average accumulation rates are the same for forest lands or former pastures and amount to 33.8 g C m⁻² y⁻¹ and 33.2 g C m⁻² y⁻¹ respectively. These rates of
organic carbon accumulation in the soil, combined with a small amount of occupied area, are insufficient to account for a significant proportion of the missing carbon in the global carbon cycle that accumulates in the soils of former agricultural lands [3, 4, 5].

Previous studies of the carbon cycle have recognized the importance of land-use changes, logging and natural regeneration of tree species, as well as associated variations in the carbon content of above-ground vegetation biomass. Radiocarbon dating of the upper humus horizons of 10 cm thickness of the zonal series of Eurasian soils from the red soil of the humid sub-tropics to the Arctic tundra gave characteristic periods of organic matter formation in the range of 60-350 years. Thus, the dominant part of the organic matter of the upper fertile soil layers is deposited there for a rather short time. Only removed from the surface or buried organic substrates can be preserved for centuries and even millennia, as evidenced by radiocarbon dating of individual fractions of soil humus. Natural soils quickly lose organic carbon when they are involved in agricultural circulation. Revealing the role and fate of the organic matter of the soil was a critical issue for scientists. There is much debate about definitions of soil organic matter among researchers. It is believed that the amount of organic carbon contained in a particular soil is a function of the balance between the rate of deposition of plant residues in the soil and the rate of mineralization of residual carbon of soil biota. However, the organic matter in the soil is always in a very dynamic condition, where biological and plant remains are constantly being transformed. The mechanisms of biological stabilization of organic carbon in the soil depend on the decomposition of the mineral phase of the soil and the chemical structure of organic residues added to the soil. A fairly accurate integral indicator of organic matter quality, on which the intensity of its decomposition depends, is the ratio of carbon to nitrogen. Plant residues with a wide ratio of carbon to nitrogen do not provide sufficient nitrogen for the metabolism of microorganisms at their high activity. Numerous studies have shown differences in the change of organic matter at different stages of soil restoration to the natural state after the cessation of active agricultural use.

The regional climate has the greatest impact on carbon storage. It is noted that primary productivity, biomass, and soil carbon content are associated with warm, humid climates and are limited in warm, dry climates, while warm temperatures are also associated with higher rates of decomposition and reduced soil carbon storage [6]. Studies conducted in Sweden showed that former arable soils had higher pH, higher nitrate concentrations and higher soil density compared to natural soils under the forest. However, there was lower organic matter and lower concentrations of ammonium in the topsoil (0-5 cm) and these differences decreased with soil depth. Previous land use is a major factor contributing to changes in Corg in the soil after reforestation. On the former arable lands, the change of Corg. differed between the soil horizons and was significant up to 20 % in the soil layer 0-10 cm. Afforestation of former meadows had a small negative effect, as indicated by a slight change in Corg. after land use change in the region. Studies conducted in the Czech Republic on land with restored woody vegetation showed that the content of organic matter in the upper layer of the soil mineral horizon, compared with arable soils, increased significantly. Soil development has resulted in an increase in total carbon content from 1.6-1.8% to 15%, with a range of 4.2 to 15.2% [7]. The results of fallow lands study in Latvia confirm the theory that after afforestation in the long term, the soil accumulates organic carbon (Corg.). During the first 30 years, the content of Corg. in the upper soil layer did not increase and ranged from 42 to 43 t/ha -1 [8]. A more rapid increase in the content of Corg was observed where the age of forest plantations exceeded 30 years and the average content of Corg in plantations aged 31-60 years was 51.3 t/ha -1.

A study conducted in Lithuania showed that the restoration of pine on nutrient-poor sandy soils could lead to an increase in the stocks of Corg. in the soil for a short period compared to the deposits of arable land without natural renewal [9]. The content of organic carbon on fallow arable land (3.81 kg cm-2) was 1.7 times less than in pine plantations (6.52 kg cm-2). It was concluded that the positive effect of reforestation on soil Corg. stocks is more pronounced in soils of arable land than in pastures or natural pastures. It is assumed that broad-leaved trees have a greater ability to restore Corg. in the soil than conifers. Restoration of woody vegetation in the boreal climatic zone leads to small losses of
organic soil carbon compared to other climatic zones, probably because trees grow slower in these conditions, although this does not exclude gains over time after conversion.

In the boreal zone of Russia the most significant transformation of soil properties in the conditions of changing vegetation was revealed for poor sandy soils of the southern taiga [10]. The degree of change in the content and reserves of organic carbon, enrichment of humus with nitrogen and acidity in the soil layer from 0 to 20 cm during postagrogenic evolution decreases from North to South.

Bringing the arable lands out of agricultural use is caused, as a rule, by economic reasons, and it is explained by a lower level of expected income over expenses on growing crops. Such a situation emerges due to a decrease in soil fertility as a result of its long-term exploitation (“soil fatigue”), caused by a number of reasons: permanent agriculture ( monoculture ), insufficient efficiency of crop rotation and green manuring applied, limited introduction of organic fertilizers, that is, everything that ensures the supply of organic residues in the soil, the decomposition of which adds to the stock of humus [11]. Studies conducted show that arable lands are undergoing the most significant deterioration of natural soil fertility. In the first period after the cessation of land use, it goes through the stage of eluvial-gley process. It consists in the destruction of the humus horizon and compaction of the remaining soil. Erosion processes occur, in the form of flushing the upper soil horizon to the bottom of the hills and ridges where swamping processes begin. In addition, from top to bottom, the thickness of the remaining part of humus decreases due to cramping and indenting, soil density and humidity grow.

In the North-West of Russia, after 6-7 years after the withdrawal of the site from economic use, the restoration of the morphological appearance of disturbed soils can begin: low-power sod (0.5 – 1 cm) appears in the watershed areas and up to 4 cm in the lower part of the slope. In various landscape positions, the restoration of the humus horizon begins: in the upland areas, it passes through the sod process; in the lowered areas, through waterlogging. Full restoration of physical and water-physical properties of the soil in all elements of the relief takes place in 17 years. In landscape conditions of hilly-ridge relief the provision of sod-podzolic soils of light mechanical composition with humus and elements of mineral nutrition reaches the natural level not earlier than 16-17 years [12].

2. Methods & objects
The objective of this study was to determine the amount of accumulation of humus in the soil while maintaining the natural conditions of the soil-forming process without any human intervention. The objects of the study were unused agricultural land and adjacent sparse deciduous stands, vacant lots, glades on which soil samples were taken. To perform this task, samples of the most common sod-podzolic soils of the South-West of the Leningrad region in Gatchina, Luzhsky and Tosnensky administrative districts were collected and analyzed (59.5407,30.8777; 58.7470,29.8665; 59.5652, 30.1282).

The mixed soil sample was composed of at least 15 individual samples. The sample weight of 250-300 grams. In the selected soil samples, the content of organic matter, acid-base indicators were determined, the granulometric composition was specified. The humus content was determined by the Tyurin method in the Nikitin modification. Determination of granulometric composition is carried out with a Pipette of N. A. Kachinsky. Soil pH was measured by potentiometric method.

3. Results & Discussion
The results of the study showed that the main factor in the evolutionary development of the soil-forming process is the vegetation cover. In addition, the physical conditions of soil formation affect the accumulation of humus, the relief, soil-forming rock, water-air properties of the soil, heat and humidity supply.

The processes of accumulation, movement and decomposition of humus are the basis of soil formation. Each plant formation corresponds to its own type of soil humus, characterized by certain limits of its quantitative accumulation and qualitative composition. The quantitative accumulation of humus is determined by the size of the annual intake into the soil of both ground litter and the
underground part (roots) of the vegetation cover. The nature of biological and biochemical transformations of these residues depends on the composition of microorganisms, the direction of microbiological processes, and, finally, on the intensity of decomposition of the humus itself [3]. Multifactorial dependence of humus formation does not allow to reliably simulate the process of transformation of organic residues and accumulation of humus in areas previously used for agricultural production. For this reason, only a simplified version can be presented: the relationship of humus accumulation with the most stable features of parent rock – clay fraction content in parent rock and soil acidity [3]. For drained soils of the meadow-forest sod-podzolic zone, this dependence can be expressed by the formula:

\[ C_{\text{hum}} = \log(\% \text{ Cl.}) \times \text{pH}_{(\text{KCl})} \times 5.8 \]

where:
- \( C_{\text{hum}} \) – mass of carbon (humus) of organic matter in the 0-20 cm layer of soil in tons ha\(^{-1}\);
- \( \log(\% \text{ Cl.}) \) – the logarithm of percentage (%) of the content of physical clay (particles d <0.01 mm) in the soil forming rock pH (KCl) – exchange (salt) acidity 5.8 – conversion factor of soil organic matter weight into soil humus carbon (\( C_{\text{hum}} \)) expressed in tons ha\(^{-1}\).

Humus expressed by means of carbon weight (\( C_{\text{hum}} \)) is a commonly accepted format used in calculating the accumulation, transformation and movement of organic matter carbon in the biosphere. The results of \( C_{\text{hum}} \) determination in the 0-20 cm layer of soil, depending on the clay fraction content and soil acidity, are given in table 1. The most widely used indicator of soil fertility is the percentage of humus in the 0-20 cm layer of soil. This indicator can be calculated by weight of \( C_{\text{hum}} \) in the 0-20 cm layer of soil expressed in tons/ha (table 1):

\[ \text{humus} \% = \frac{C_{\text{hum}} \text{ in the 0-20 cm layer}}{20} \times 0.8 \times \text{specific density} \]

where:
- \( C_{\text{hum}} \) – soil carbon mass of humus in the 0-20 cm layer of soil in tons/ha (table 1);
- 20 – 0-20 cm layer of soil;
- 0.58 – conversion factor of \( C_{\text{hum}} \) in the humus content in the soil expressed in % (carbon (C) content in humus is 58 %) specifically density. – average specific density of soil (g/cm\(^3\)) for the whole 0-20 cm layer:
  - 1.2 – of sandy loam soil;
  - 1.15 – light loamy soil;
  - 1.1 – loamy soil.

The results of the calculation of % humus in a layer of 0-20 cm soil are given in table 2.

For comparative characteristics, indicators of humus stocks in the upper 20 cm layer of soil given in table 3 are used.

**Table 1.** Stock of humus carbon \( C_{\text{hum}} \), (tons ha\(^{-1}\)) in the 20 cm soil layer depending on the clay fraction content (%) and acidity (\( \text{pH}_{(\text{KCl})} \)) (%)

| Clay, \( \% \) | \( \text{pH}_{(\text{KCl})} \) |
|-----------------|-------------------------|
|                 | 3.6 | 3.8 | 4.0 | 4.5 | 5.0 | 5.5 | 6.0 | 6.5 |
| 15              | 24.6 | 26.0 | 28.2 | 30.8 | 34.2 | 37.6 | 41 | 44.5 |
| 20              | 27.1 | 28.6 | 30.2 | 33.9 | 37.9 | 41.4 | 45.2 | 49.0 |
| 25              | 29.2 | 30.9 | 32.5 | 36.6 | 40.6 | 44.6 | 48.7 | 52.8 |
| 30              | 30.9 | 32.6 | 34.3 | 38.6 | 42.9 | 47.2 | 51.5 | 55.8 |
| 35              | 32.2 | 33.9 | 35.8 | 40.2 | 44.6 | 49.1 | 53.6 | 58.1 |
| 40              | 33.4 | 35.3 | 37.1 | 41.8 | 46.4 | 51.0 | 55.7 | 60.3 |
Table 2. Humus content in the 20 cm soil layer depending on the clay fraction content (Cl,%) and acidity (pH_{KCl}), %

| Clay, % | Values of pH_{KCl} |
|-------|---------------------|
|       | 3.6 | 3.8 | 4.0 | 4.5 | 5.0 | 5.5 | 6.0 | 6.5 |
| 15    | 1.8 | 1.9 | 2.0 | 2.2 | 2.5 | 2.7 | 2.9 | 3.2 |
| 20    | 1.9 | 2.1 | 2.2 | 2.4 | 2.7 | 3.0 | 3.2 | 3.5 |
| 25    | 2.2 | 2.3 | 2.4 | 2.7 | 3.0 | 3.3 | 3.7 | 4.0 |
| 30    | 2.3 | 2.4 | 2.6 | 2.9 | 3.2 | 3.5 | 3.9 | 4.2 |
| 35    | 2.5 | 2.7 | 2.8 | 3.1 | 3.5 | 3.8 | 4.2 | 4.6 |
| 40    | 2.6 | 2.8 | 2.9 | 3.3 | 3.6 | 4.0 | 4.4 | 4.7 |

Table 3. Stock of humus in the 20 cm soil layer depending on the clay fraction content (Cl,%) and acidity (pH_{KCl}), tons ha$^{-1}$

| Clay, % | Values of pH_{KCl} |
|-------|---------------------|
|       | 3.6 | 3.8 | 4.0 | 4.5 | 5.0 | 5.5 | 6.0 | 6.5 |
| 15    | 42  | 45  | 47  | 53  | 59  | 65  | 70  | 77  |
| 20    | 46  | 50  | 52  | 58  | 65  | 71  | 78  | 85  |
| 25    | 50  | 54  | 56  | 63  | 70  | 77  | 83  | 91  |
| 30    | 54  | 56  | 59  | 66  | 74  | 82  | 89  | 96  |
| 35    | 56  | 58  | 62  | 71  | 77  | 85  | 93  | 100 |
| 40    | 58  | 61  | 64  | 72  | 80  | 88  | 96  | 104 |

The data obtained show a high correlation between the content of humus in the former arable soil horizon with clay fraction (R=0.87-0.93) and pH_{KCl} (R=0.85-0.90) in the former surface horizon. These humus reserves in the soil belong to non-forest lands with a formed growth cover and a well-defined morphology of the soil profile. In other words, the studied lands have an ecosystem close to the meadow phytocenosis, which will be approached by the developing and changing biocenosis of arable lands that have come out of agricultural use. Errors in determining the stock of humus do not exceed 10-15%, if samples are taken from the arable layer of a functioning field. They are explained by various reasons. In field work it can be soil sampling from fields of different soil moisture regime, or different granulometric composition. In laboratory studies – these are the conditions for the preparation of soil samples (drying, grinding, sifting storage), failure to meet deadlines for using the prepared reagents Before starting soil sampling on fallow lands, it is necessary to conduct a survey and make measurements of the power of genetic horizons in each soil difference identified during the survey. On the lands lying in the fallow for a long time (over 20 years), soil sampling should be done according to genetic horizons if they are well expressed, and with their indeterminacy – by the 10 cm layers. If this condition is not met, the calculated stocks may significantly differ from the actual accumulation. Thus, for example, the upper 20 cm layer of arable soil has a density of 1.1 and humus stock of 65 tons ha$^{-1}$. The soil of post-agrogenic lands in fallow over 20 years old, having no clearly expressed genetic horizons, has the same level of fertility. In the upper 10 cm layer of the fallow soil, humus stock is 50 tons ha$^{-1}$, while in the 10-20 cm layer – 15 tons ha$^{-1}$; specific density of the upper layer – 0.8, and of the 10-20 cm layer – 1.2. The total stock of humus in the 0-20 cm layer will be 65 tons ha$^{-1}$. However, if we limit ourselves to the sampling from only one layer, and make recalculation for the whole 20 cm layer, then data scattering on the stock of humus in the 0-20cm layer will be from 30 to 100 tons ha$^{-1}$, which distorts the true content.
4. Conclusion
The accumulation of organic matter on postagrogenic lands occurs differently at different successional stages since the formation of different vegetation cover makes adjustments to this process.

Errors in determining the stock of humus on postagrogenic lands can exceed 30%. The main reason is the differences in the specific density of the soil and the unequal content of humus in the genetic horizons of fallow soil compared to the arable layer of the field, where these horizons are mixed into a homogeneous mass. From this it follows that the methodology for the selection of soil samples from arable land and from post-agrogenic lands should be different.

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