The nature of organic carbon and total nitrogen distribution in the fractions of leached chernozem aggregates and gray soil in Western Siberia

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Abstract. The features of the accumulation and distribution of organic carbon and nitrogen in the aggregates of the arable layer of leached chernozem (Luvic Voronic Chernozems) and gray forest soil (Luvic Retic Greyzemic Phaeozems) were evaluated. After dry sieving in structural separates of dimensional fractions >10, 10-5, 5-2, 2-1, 1-0.25, and <0.25 mm, the content of organic carbon and total nitrogen was determined in the laboratory. It was found that chernozem and gray forest soil significantly differed from each other in organic carbon in all fractions of structural separates. Lumpy aggregates (>10 mm) and fine earth (<0.25 mm) were characterized by an average spatial variability (CV up to 21%) of organic carbon and total nitrogen content. In chernozem arable layer, the maximum content of organic carbon and total nitrogen was in size fractions from 5 to 0.25 mm, whereas in gray forest soil – from 10 to 2 mm. Maximum value of C:N in gray forest soil was 16.0 units in aggregates with dimensions less than 0.25 mm, and in chernozem – in the lumpy fraction (> 10 mm), where the ratio was 15.1 units it was revealed that the content of organic carbon in structural units depends on the soil type by 21%, and on the dimensional fraction by 37%. The total nitrogen content is determined by 20% by the soil type and 36% by the size of structural aggregates.

1. Introduction
Agrophysical properties of the soil are legitimately considered the most important fertility indicator, the main of which is the structural and aggregate composition. The structure is understood as the physical structure of the soil horizon, which is expressed by the size and shape of aggregates and conditioned by the nature of the relationship at different structure formation levels [1, 2]. During evolution, all mineral soils undergo all stages of structure formation, starting from microaggregates and ending with the formation of macroaggregates, on which all, without exception, modern regimes (water, air, nutrient) depend. Granulometric and mineralogical composition act as the structure formation basis. In the upper part of the soil profile, humic substances and their chemical composition become important. It is generally accepted that they determine soil resistance to the effects of adverse environmental factors [3, 4, 5]. This is extremely important for agriculture, where the impact on the soil is systematic. The stable structure of the humus horizon optimizes the processes of organic matter
mineralization and humification, which affects the nutritional regime and generally provides potential fertility.

Currently, the traditional approach to studying soil structure is gradually changing from a quantitative assessment of the size of soil aggregates to a qualitative one, which is expressed in the content of humus substances and nitrogen in each fraction. A quantitative and qualitative approach to the study of soil structure, especially arable horizons, allows to model fertility and make long-term forecasts of fertility dynamics in different natural and climatic zones. On the other hand, understanding the relationship between the sizes of soil aggregates and the content of two chemical elements carbon and nitrogen in each individual fraction, makes it possible to interpret data quickly and accurately on the nutritional regime and humus state of arable soils by quantitative indicators in the form of structural and aggregate composition.

The territory of Western Siberia is considered a zone of risky farming. Short summers and harsh winters require farmers to make quick decisions on growing crops and developing a farming system for them. The achievements of modern breeding, agrochemistry, and agriculture have ensured the advancement of agriculture to the north, where 100 years ago no one thought of cultivating grain crops, developing animal husbandry and poultry farming [6, 7, 8, 9]. In digitalization era, it became possible to develop optimization models on a mathematical basis, which made it possible to increase the productivity of arable land with expanded fertility reproduction [10].

The purpose of the study is to identify the nature of the organic carbon and total nitrogen distribution in various fractions of the structural composition of the arable horizon of leached chernozem and gray forest soil in Western Siberia.

2. Materials and Methods

The work used plots with an area of 5 hectares, geographically fixed in the fields in production conditions. Sampling was carried out in 2021. Samples of leached chernozem (Luvic Voronic Chernozems) [11] were selected on the field of the experimental farm of the State Agrarian University of the Northern Trans-Urals (Uteshevo village, Tyumen region, 57°10′00″ N; 65°19′18″ E). The farm is in the northern forest-steppe. Since 2002, a grain-fallow-hoed rotation with alternating crops has been used in the field: seeded fallow (pea-oat mixture for haylage), spring wheat, corn for silage, spring wheat, oat. Samples of gray forest soil (Luvic Retic Greyzemic Pheaozems) [11] were taken from the field of the peasant farm "RUS" (Berezovka village, Nizhne-Tavdinsky district, Tyumen region (coordinates: 57°47′59.94″ N; 65°35′37.18″ E). The farm is in the subtaiga zone. Grain-fallow crop rotation (seeded fallow, spring wheat, spring wheat, oat) is used for the field. The distance between the stations is 75 km.

The soil treatment system is a dump multi-depth one. Under the seeded fallow and corn – plowing to a depth of 25-30 cm; under grain crops – 22 cm. The system of pre-sowing tillage and crop care is traditional for the Northern Trans-Urals.

Sampling was carried out in the third decade of July. On a 5-hectare field plot, 10 samples were taken to the depth of the arable layer (0-30 cm). This made it possible to establish the features of spatial variation and to assess the reliability of the results obtained. As a sample, soil weighing 5-6 kg was taken out and placed in a separate bag. This made it possible to establish as accurately as possible the structural and aggregate composition closest to field conditions. Then the soil samples were gradually dried to an air-dry state. During the drying process, a weak mechanical impact was applied to the soil three times (falling from a height of 1 meter) to destroy large lumps (more than 5 cm). An air-dry soil sample was sifted through a sieve column (Savvinov's method) with separation into dimensional fractions: >10, 10-5, 5-2, 2-1, 1-0.25, <0.25 mm [12]. After fractionation, soil samples were selected for analysis for organic carbon and total nitrogen. The upper part of the profile of leached chernozem and gray forest soil of the Northern Trans-Urals do not contain carbonates, therefore, the determination of mineral carbon in the arable layer was not carried out.

The content of organic carbon was determined by its oxidation with a solution of potassium bicarbonate in sulfuric acid and subsequent determination of trivalent chromium by photometric
method (GOST 26213-91). Total nitrogen was determined by wet digestion of the sample with concentrated sulfuric acid followed by Kjeldahl titration (GOST R 58596-2019).

Statistical processing and variance analysis of chemical test results were carried out using Microsoft Excel. The variability of the studied indicators was carried out according to the scale proposed by V.I. Savich [13], which is presented in Table 1.

Table 1. Evaluation of the accuracy of determining indicators by the magnitude of the coefficient of variation (CV), %.

| Coefficient of variation (Savich, 1971) | Variation, (Savich, 1971) | Mark |
|----------------------------------------|---------------------------|------|
| 0 – 5                                   | Insignificant             | 10   |
| 6 – 10                                  |                           | 9    |
| 11 – 15                                 | Small                     | 8    |
| 16 – 20                                 |                           | 7    |
| 21 – 30                                 | Medium                    | 6    |
| 31 – 40                                 |                           | 5    |
| 41 – 45                                 | High                      | 4    |
| 46 – 50                                 |                           | 3    |
| 51 – 60                                 |                           | 2    |
| >60                                     | Very high                 | 1    |

3. Results and Discussion

As our research has shown, the arable horizons of leached chernozem and gray forest soil have no fundamental differences in structure. The content of agronomically valuable fractions (0.25-10.0 mm) with dry sieving is the same – 66%, which corresponds to good structurality. The variability in the field is insignificant – the coefficient of variation is 4-5% (Table 2). Fractional analysis of structural separations revealed differences between the studied soils. The content of lumpy aggregates (>10.0 mm) in the arable layer of chernozem on average in the sample is 29.4±3.0 %. The variability of values in the field reaches 10%, which corresponds to 9 points of spatial variability according to Savich. In gray forest soils, the content of lumpy aggregates is lower – 19.4 ±3.1%, which is due to the lower humus content of this fraction. The coefficient of variation is 16%, which indicates a higher degree of heterogeneity of the arable horizon with respect to chernozem.

The part of the soil that does not belong to macroaggregates (<0.25 mm), as well as the lumpy fraction, characterizes the structural and aggregate composition. For optimal structure formation, it is required that a small part of microaggregates not glued into large aggregates be present in the soil [14, 15]. In the arable layer of chernozem, the content of structural separations with dimensions less than 0.25 mm is 4.9±1.4%, but with an average degree of variability (CV=28%). In virgin chernozems, the heterogeneity in this indicator is significantly lower, as evidenced by our studies [16]. This is confirmed by colleagues from Kurgan and Krasnoyarsk [17, 18].

As a result of long-term anthropogenic influence, the arable horizon of gray forest soil has a more dispersed appearance. The fraction content with dimensions less than 0.25 mm is 14±2.7% with a variation coefficient of 19%. This fact is explained by the lower content of humus substances and silty particles that provide the primary structure formation of soil aggregates [19].

The analysis of organic carbon and nitrogen showed that in the lumpy aggregates of chernozem their content is 3.19±0.45 and 0.21±0.03%, respectively. The intra-field variation is small (CV=14-16%). In gray forest soils, lumpy aggregates contain fewer of these elements: organic carbon - 2.22±0.44, nitrogen - 0.21±0.05. The high coefficient of variability shows that the values on
chernozems and gray forests overlap, thereby indicating the absence of influence of soil type in carbon and nitrogen distribution nature in lumpy aggregates.

In fine earth, the size of which is less than 0.25 mm, the content of organic carbon in chernozem reaches 3.47±0.59% with a coefficient of variation of 17%. According to many researchers, humus substances and finely dispersed plant residues are the main part of microaggregates. Nevertheless, when comparing the 1.0-0.25 mm fraction, it turns out that the carbon content there is higher – 5.17%. This gives us the right to assert that in chernozem soils, the fraction of aggregates with dimensions less than 0.25 mm has a mineral composition, as in other soils. This is also confirmed by the content of total nitrogen – 0.31%, whereas in the 1.0-0.25 mm fraction it is significantly higher (0.54%).

The deficiency of plant residues in the formation of gray forest soils is especially visible in the fraction that does not belong to macroaggregates. In particles with sizes less than 0.25 mm, the organic carbon content is 1.42%, which is almost 2.5 times lower than the chernozem values. This indicates that the possibility of primary structure formation due to humus in gray forest soil is minimal. The main part of this fraction is represented by the detrital products of the soil mineral part. As the research of V.L. Tatarintsev shows, this fraction consists of minerals of the free silica group [20]. A fraction with dimensions less than 0.25 mm in the arable layer of gray forest soil contains a minimum amount of total nitrogen – 0.09±0.02% with a coefficient of intrafield variability of more than 20%.

The analysis of agronomically valuable fractions of the chernozem arable layer (0.25-10.0 mm) showed that aggregates with sizes 1.0-2.0 and 0.25-1.0 mm are most enriched with organic carbon and total nitrogen. Their content reaches 5.17 and 0.54%, respectively. In larger aggregates, the organic carbon content is relatively stable – its average value is 3.82%. The total nitrogen manifests similarly. Fractions 5.0-10.0 and 2.0-5.0 are allocated in gray forest soils, where the organic carbon content reaches 4.39±0.48 and 3.99±0.24%, respectively. The maximum amount of total nitrogen 0.32-0.35% was found in the same fractions.

The obtained results of elemental analysis prove that in chernozems humus formation mainly occurs in aggregates with sizes 0.25-2.0 mm, whereas in gray forest soils – in larger structural units – 2.0-10.0 mm. This is the scientific justification for choosing a tillage system. To stabilize humus formation, it is necessary to maintain the level of fraction formation with sizes 0.25-2.0 mm by mechanical treatments, whereas on gray forest soils it is necessary to minimize the number of technological operations to prevent the grinding of structural aggregates of the arable layer.

The carbon to nitrogen ratio characterizes the humus qualitative composition. The higher the value, the less high-quality humus is formed from the fertility point of view. Therefore, it is important to create conditions for the formation of soil organic matter with a ratio of 9-12 units. At lower values, it is likely that mineral compounds (nitrates, nitrites, ammonium) that are not part of humus will predominate in the nitrogen composition [21].

As our studies have shown, the maximum C:N in the studied soils falls on two diametrically opposite fractions. In chernozems, a lumpy fraction with a size of more than 10.0 mm is allocated, in which C:N is 15.1 units (Figure 1). In gray forest – fine earth (<0.25 mm) - 16.0, which indicates a very low nitrogen content of organic matter in this fraction.

By carbon to nitrogen ratio, the agronomically valuable fraction (0.25-10.0 mm) can be divided into two groups: 5.0-10.0 mm with a ratio of 13 units, which makes it like the lumpy fraction (>10 mm) and 0.25-5.0 mm, where this indicator varies from 9.6 to 11.1 units.

In the arable layer of gray forest soil, the agronomically valuable fraction (0.25-10.0 mm) by carbon to nitrogen ratio is divided differently: the first fraction is from 1.0 to 10.0 mm, where C:N varies from 12.2 to 13.1, which also makes it similar to the quality of humus substances in lumpy fractions. In the remaining part (0.25-1.0 mm), this indicator decreases to 10.9 units. Thus, Figure 1 confirms that the formation of humus is not the same in different fractions of the structural and aggregate composition. If humus formation in chernozem is active in structural separations ranging in size from 0.25 to 5.0 mm, then in gray forest soils – only in a fraction of 0.25-1.0 mm.
Table 2. The content of organic carbon and total nitrogen in various fractions of aggregates of the arable layer of chernozems and gray forest soils, %.

| Soil                | Size of fractions, mm | Content of aggregates | Organic carbon | Total nitrogen |
|---------------------|-----------------------|-----------------------|----------------|----------------|
|                     |                       | m ± s\(^a\) CV\(^b\) | m ± s CV       | m ± s CV       |
| leached chernozem   | >10                   | 29.4±3.0 10           | 3.19±0.45 14 | 0.21±0.03 16 |
|                     | 10-5                  | 20.7±1.6 8            | 3.83±0.53 14 | 0.29±0.04 14 |
|                     | 5-2                   | 21.1±1.5 7            | 3.82±0.57 15 | 0.35±0.04 19 |
|                     | 2-1                   | 12.5±1.2 10           | 4.75±0.69 15 | 0.42±0.04 17 |
|                     | 1-0.25                | 12.8±1.5 12           | 5.17±0.60 12 | 0.54±0.08 14 |
|                     | <0.25                 | 4.9±1.4 28            | 3.47±0.59 17 | 0.31±0.05 17 |
| gray forest         | >10                   | 19.4±3.1 16           | 2.22±0.44 20 | 0.21±0.05 24 |
|                     | 10-5                  | 15.5±1.9 12           | 4.39±0.48 11 | 0.35±0.04 12 |
|                     | 5-2                   | 21.4±1.9 9            | 3.99±0.24 6  | 0.32±0.03 11 |
|                     | 2-1                   | 16.9±1.6 10           | 3.34±0.54 16 | 0.26±0.05 18 |
|                     | 1-0.25                | 12.3±1.9 16           | 2.72±0.31 11 | 0.25±0.04 15 |
|                     | <0.25                 | 14.5±2.7 19           | 1.42±0.23 17 | 0.09±0.02 21 |

\(^a\) m ± s – average value ± standard deviation.
\(^b\) CV – coefficient of variation, %.

Figure 1. Ratio of organic carbon to total nitrogen (C:N) in various fractions of aggregates of the arable horizon of chernozem and gray forest soil.
To determine the reliability of the results obtained and to identify the strength of the influence of each factor, a two-factor analysis of variance was carried out. The type of soil was taken as factor A; factor B – fractions of aggregates. After processing the organic carbon data, the following results were obtained. The average error was 0.2%, the accuracy of the experiment was 4.6% with the smallest significant difference of 0.5%.

It was found that the carbon content is influenced by both the type of soil (factor A) and the structural and aggregate composition fractions during dry sieving (factor B). Calculations have shown that the soil type determines the content of organic carbon in structural units by 21% (Table 3). 37% is affected by the size of fractions of soil aggregates. The interaction of AB factors reduces the indicator of influence power to 24%. In all cases $F_{\text{fact}} > F_{\text{teor}}$, and the Student's criterion is 2.0.

During the dispersion analysis, it was also found that the total nitrogen content in the structural aggregates of the arable layer depends on the type of soil by 20% ($F_{\text{fact}} > F_{\text{teor}}$) and 36% of the size of soil particles. The indicator of the strength of influence from the interaction of these factors is 28%. The smallest significant difference in experiment is 0.05%.

4. Conclusions

During the research, it was found that the macroaggregates of the arable layer of leached chernozem and gray forest soil are heterogeneous in the distribution of organic carbon and total nitrogen. The particles formed during plowing with a size of <0.25 mm have a similar carbon content with aggregates >10 mm, which allows us to assume the formation of a lumpy structure due to the fine earth bonding. The maximum carbon content is observed in the size fractions: in chernozem – 10-0.25 mm; in gray forest – 10-1.0 mm. A tendency to increase the total nitrogen content with a decrease in the size of aggregates in the range of agronomically valuable structure (0.25-10.0 mm) from 0.29 to 0.54% was revealed. In gray forest soils, the maximum nitrogen falls on a fraction of 10.0-1.0 mm. To optimize the humus formation of arable land, it is necessary to develop a soil tillage system: for chernozems – ensuring the grinding of lumpy aggregates to an agronomically valuable structure; for

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Table 3. The results of the dispersion two-factor analysis of the studied indicators of chernozem and gray forest soil (factor A - soil type; factor B - fractions of aggregates).

| Source of variation | Sum of squares | Degrees of freedom | Variance | $F_{\text{fact.}}$ | $F_{\text{teor.}}$ | Indicator of the power of influence, % |
|---------------------|---------------|--------------------|----------|-------------------|-------------------|----------------------------------------|
| **Structural and aggregate composition** | | | | | | |
| Factor A | 0.004 | 1 | 0.004 | 0.001 | 8.6 | 0 |
| Factor B | 3168 | 5 | 634 | 139 | 2.3 | 66 |
| AB interaction | 1198 | 5 | 240 | 52.7 | 2.3 | 25 |
| **Organic carbon** | | | | | | |
| Factor A | 31.4 | 1 | 31.4 | 122.0 | 4.0 | 21 |
| Factor B | 55.3 | 5 | 11.1 | 42.9 | 2.3 | 37 |
| AB interaction | 35.9 | 5 | 7.2 | 27.9 | 2.3 | 24 |
| **Total nitrogen** | | | | | | |
| Factor A | 0.3 | 1 | 0.3 | 130.4 | 4.0 | 20 |
| Factor B | 0.6 | 5 | 0.1 | 46.2 | 2.3 | 36 |
| AB interaction | 0.5 | 5 | 0.1 | 35.7 | 2.3 | 28 |

To determine the reliability of the results obtained and to identify the strength of the influence of each factor, a two-factor analysis of variance was carried out. The type of soil was taken as factor A; factor B – fractions of aggregates. After processing the organic carbon data, the following results were obtained. The average error was 0.2%, the accuracy of the experiment was 4.6% with the smallest significant difference of 0.5%.

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gray forest soil – to minimize mechanical impact, thereby ensuring the formation of macro aggregates with sizes from 2 to 10 mm.

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