Fertility of agrogenic and postagrogenic chernozems of Western Siberia

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Abstract. In Western Siberia, agricultural land resources have been actively used for many decades. Each year, the anthropogenic load increases, although the chernozem of Siberia is considered the youngest relative to the European part of Russia. Therefore, a problem has arisen - soil fatigue expressed by a decrease in crop yields, despite the introduction of mineral fertilizers. To solve this problem, it is necessary to transfer part of arable lands of Siberia to the category of grass fallow, where the main indicator of fertility, the humus state, is being restored. The aim of the research was to study the dynamics of the humus content and its enrichment with nitrogen. The research was carried out at the station of the Department of Soil Science and Agricultural Chemistry of the State Agricultural University of Northern Trans-Urals, which is located in the northern forest-steppe of the Tyumen region. The station was founded in 1968 and still exists. As a result of the studies, it was found that the five-year grass fallow is characterized by a slight increase in the content of humus in the upper layer. Humus reserves in the layer of 0-30 cm increased by 9 tons, which corresponded to an annual accumulation of 1.8 t/ha. However, this is not enough to restore the humus state of old arable chernozems in Western Siberia. The total nitrogen content in the five-year grass fallow increased from 0.18-0.30 to 0.24-0.36%, which exceeds the values of arable chernozems. After 15 years, the postagrogenic chernozem of grass fallow was characterized by a high humus content in the layer of 0–20 cm (7.8%) and nitrogen accumulation in organic matter up to 0.4% with the C:N ratio of 8.2–11.6. It has been established that over 15 years, postagrogenic chernozems of Western Siberia cannot restore the humus state to the level of virgin land analogues.

1. Introduction

Agriculture of the Russian Federation is actively moving to the northern regions, gradually reclaiming new soils. This is due to the active contribution of science and the emergence of new technical solutions. The scientifically-based farming system and achievements in crop breeding made it possible to create a reliable agricultural industry in Western and Eastern Siberia, despite the unfavorable soil and climatic conditions [1, 2, 3, 4, 5, 6]. With the northwarding of agriculture, a serious problem arose, which is associated with the high intensity of the use of land resources in Siberia. The main burden lay on chernozem soils, as the most fertile, but the least stable in comparison with European analogues. Those involved in agricultural circulation began to rapidly lose humus, which negatively affected their properties and resistance to erosion [7, 8, 9,10]. The use of humic, microbiological preparations and mineral fertilizers reduce the effects of a strong anthropogenic load, but cannot completely neutralize them [11, 12, 13]. Therefore, it is necessary to provide for such a technology as
the transfer of depleted soils to fallow ones in the system of Siberian agriculture. This makes it possible to restore fertility and prevent the complete degradation of the fertile soils of Siberia. However, the question always arises of how long it is necessary to remove soil from agricultural turnover. It is rather difficult to clearly answer this question - it all depends on the degree of plowing of the soil and the rate of development of herbaceous vegetation on it.

Organic matter is an integral part of the soil fertility, in which the main nutrients are located, affects the agrophysical properties of the soil, its water, air and thermal conditions. The capacity of cation exchange, the accumulation of phosphorus in the organic form, and also microelements involved in the biological cycle depend on the presence of humus. Under natural conditions, an equilibrium relationship is formed between the input and decomposition of organic matter in the soil-plant system. This balance is disturbed when plowing virgin lands and grass fallow plots. The isolation of part of the plant matter (harvesting) leads to a sharp decrease in the flow of organic matter into the soil. In addition, the root mass of crops, especially cereals, is 3-5 times less than perennial herbaceous plants, which inevitably leads to a deficiency of plant residues necessary for humification [14]. Also, the process of mineralization of organic matter is intensified on the arable land due to increased aeration [15].

Numerous studies have shown that the most intense loss of humus occurs in the first 10-15 years after plowing [16, 17]. Later, the process slows down, and humus formation is stabilized, taking into account modern conditions, and only a sharp change in conditions (increase in doses of mineral fertilizers, irrigation, transfer to another soil treatment system) can again lead to a shift in equilibrium.

To stabilize humus formation and expanded reproduction of fertility, the use of manure is traditionally recommended. However, studies have shown that the efficiency of organic fertilizers is shown only on low humus soils or with long-term application of 50-60 t/ha [16]. The most rational way to restore fertility is to transfer the soil to the grass fallow.

2. Materials and methods

The study of changes in the fertility state of leached chernozems in the “arable land- grass fallow” system was carried out at station No. 1 of the Department of Soil Science and Agricultural Chemistry, which was also established in 1968 on old arable chernozem. The territory is a northern forest-steppe zone of the Trans-Urals, characterized by a wavy flat relief. On a geomorphological scale, it is located on the fifth terrace rising above the floodplain of the Tura river. Soil-forming rocks are polynomial sandy-silty shale carbonate loams. Soil - highly leached chernozem, medium humus, thin, heavy loamy on shale carbonate loam.

Until 1993, it was used as arable land. After intermediate studies, it was sown with perennial grasses (legume-cereal mixture) and transferred from arable land to the category of mowing grass fallow. In 1998 and 2008, a series of studies was again conducted to identify the restoration of fertility of the old arable chernozem. In 2008, a section of leached virgin chernozem, which is located on the territory of station No. 1, was also studied to highlight the features of natural soil formation. The soil in its properties and classification does not differ from the main site of the station.

Table 1. Station No. 1. Leached chernozem, medium-thick, medium loamy. Virgin land, 2008 (description made by D.I. Yeremin).

| Horizon | Description |
|---------|-------------|
| A0      | 0-5 cm. Rooty sod. |
| A       | 5-45 cm. Black, dry, medium loamy, grainy-lumpy, compacted, with many roots. The transition is gradual. |
| AB1     | 45-59 cm. Brownish-gray, dry, heavy loamy, nuciform and finely lumpy, compacted, with many roots. The transition is clear, tongued. |
| B2      | 59-131 cm. Bight brown, fresh, heavy loamy, medium and finely nuciform, dense, with many roots, often has humic pockets and molehills, humus tongues up to 80 cm. The transition is noticeable. |
| BK1     | 131-199 cm. Light brown. The horizon is finely porous, slightly densified, fresh, and the structure is not pronounced. Middle loamy. There are roots, rarely pebbles. Effervescence from HCl. The effervescence line is uneven, tongued. Carbonates up in the form of lime nodules and carbonate... |
The organic carbon content in soil samples was studied by carbon oxidation with potassium dichromate, followed by photometric determination. Total nitrogen was determined according to the method of Kjeldahl-Iodedbuer. The results of chemical analysis were converted into humus reserves by multiplying by a factor of 1.724 and taking into account the equilibrium density of addition. Analysis of variance was carried out according to methods generally accepted in Russia.

3. Results and discussion

In 1968, the humus content in the layer of 0–20 cm of old arable chernozem was 7.6% (Table 2). The uniformity of distribution is explained by the annual moldboard plowing, during which intensive mixing of the arable horizon occurs. A layer of 20-30 cm is characterized by a sharp decrease in the content of humus to 4.1%. Such a sharp decrease in humus in the soil profile is explained by the fact that the moldboard plowing was carried out only to a depth of 20-25 cm, without affecting the subsurface horizon. This is also confirmed when describing the morphological features of arable chernozem. In the layer of 30–50 cm, the humus content was insignificant — 1.5%, which is typical for low-thick chernozem soils of the Northern Trans-Urals.

Over 25 years of using chernozem as arable land, the humus content in the layer of 0-20 cm decreased by 8.6% compared to 1968 and reached 7.0% in 1993. The deterioration of humus content is associated with a lack of plant matter, since both grain and straw were removed from the field. The subsurface layer (20-30 cm) was characterized by the absence of a significant decrease in the humus content from 4.1 to 3.9% - the deviation is within the experimental error.

Table 2. The dynamics of the humus content in leached chernozem during agricultural use, %

| Soil layer, cm | Arable land | Grass fallow |
|----------------|-------------|--------------|
|                | 1968*       | 1993**       | Changes in the content of humus by 1993, in % of 1968 | 1998        | 2008        | Changes in the content of humus by 2008, in % of 1993 | in % of 1998 |
| 0-20           | 7.6         | 7.0          | -8.6                      | 7.3         | 7.8          | 11.5                      | 6.2          |
| 20-30          | 4.1         | 3.9          | -4.9                      | 4.0         | 4.5          | 15.4                      | 12.5         |
| 30-50          | 1.5         | 1.6          | 5.1                       | 1.5         | 1.6          | 0.0                       | 6.6          |
| 50-100         | 0.6         | 0.6          | 0.0                       | 0.5         | 0.5          | -13.0                     | 0.0          |

* - data obtained by L.N. Karetin; ** - data obtained by A.G. Karyakina.

In 2008, the morphological description of the section showed that there was an improvement in the structural and aggregate composition of the arable horizon, the lumpiness characteristic of old arable chernozem soils disappeared, and a granular-finely lumpy structure corresponding to the virgin soil appeared.

In 1998, the humus content reached 7.3%, and in 2008 - 7.8%, which is 11.5% more than in 1993. Over the past 10 years, the humus content has increased from 7.3 to 7.8% - the deviation was 6.8% compared to 1998. It is necessary to pay attention to the humus content in the layer of 20-30 cm, where the humus reserves increased from 3.9 to 4.5% in 15 years, and enrichment occurred in the period 1998-2008 - the deviation was 12.5% compared to 1993. This indicates an active penetration of the root system into this layer. At a depth deeper than 30 cm, the humus state has not changed significantly due to poor penetration of the root system of perennial grasses, which is confirmed by the morphological description of the soil section.

Calculation of humus reserves makes it possible to visually assess the agricultural impact and further calculate the rate of degradation and restoration of fertility of old arable chernozems. In 1968,
the reserves in the meter layer were 298 t/ha, and 77.5% accounted for 0-30 cm. In the 30-50 cm layer, humus reserves are insignificant - 36 t/ha, which is typical for the transitional horizon of leached chernozems in the Northern Trans-Urals.

Over 25 years of moldboard plowing, reserves in the layer of 0-30 cm decreased to 214 t/ha - losses amounted to 17 t/ha, i.e. 0.7 tons per year. Loss of humus in the upper layer is explained by increased aeration of the arable horizon, which leads to increased mineralization of organic matter.

**Table 3.** The humus reserves in leached chernozem for agricultural use, %.

| Soil layer, cm | Arable land 1968 | Grass fallow 1968 | Changes in the content of humus by 1993, in % of 1968 | 1998 | 2008 |
|---------------|-----------------|------------------|--------------------------------------------------|------|------|
| 0-30          | 231             | 214              | -7.7                                             | 223  | 240  |
| 30-50         | 36              | 37               | 4.7                                              | 35   | 39   |
| 50-100        | 31              | 31               | -0.2                                             | 27   | 27   |
| 0-100         | 298             | 282              | -5.5                                             | 285  | 306  |

* - data obtained by L.N. Karetin; ** - data obtained by A.G. Karyakina.

Over five years, the humus reserves in the layer of 0-30 cm of the grass fallow site increased by 9 tons (1.8 tons per year) and reached 223 t/ha, but this is 8 tons less than in 1968. This indicates the inefficiency of the 5-year-old grass fallow land in the restoration of humus content after 25 years of use of chernozem as arable land. Despite this, the structural composition of postagrogenic chernozem began to improve. The reason for this was a change in the quality of humus [18, 19].

In 2008, reserves in the grass fallow site in the layer of 0-30 cm reached 240 t/ha, which is 26 tons more than in 1993 and 9 tons more than in 1968. Thanks to perennial herbaceous plants in the meter-long layer of leached chernozem, 24 tons of humus accumulated during 15 years, i.e. 1.6 tons per year.

Such a significant change in plant communities should radically change the qualitative composition of humus, one of the main indicators of which is the content of total nitrogen and its enrichment of humus, expressed by the ratio C: N. In 1968, the total nitrogen content in the layer of 0-20 cm was 0.34-0.35%; in a layer of 20-30 cm - 0.21% (Table 4). This indicator gradually decreases with depth, reaching minimum values in the layer of 50-60 cm - 0.10%. The increase in the total nitrogen content in the layer of 60-80 cm - 0.15-0.17% is caused by the migration processes of both labile organic substances and mineral forms of nitrogen from the overlying layers, which is confirmed by data on the arable land of 1993.

Over 25 years of using leached chernozem as arable land, the content of total nitrogen in the layer of 0-20 cm decreased to 0.28-0.30% - the deviation was 14.3-17.6% relative to the arable land of 1968. This fact is a sign of depletion of chernozem during this period [20, 21]. A decrease in the total nitrogen content was also noted in the deeper layers - 20-50 cm - 10.5-14.3% of the values of arable land in 1968.

**Table 4.** The content of total nitrogen in leached chernozem of arable land and grass fallow.

| Sampling depth, cm | Arable land 1968 | Grass fallow 1968 | Virgin land 1993 | Deviation, % relative to arable land of 1968 |
|-------------------|-----------------|------------------|-----------------|-----------------------------------|
|                   | 1998            | 2008             | 2008            | Arable land, 1993 | Grass fallow, 1998 | Grass fallow, 2008 |
| 0-10              | 0.35            | 0.30             | 0.34            | 0.47               | -14.3               | -2.9                | 14.3               |
| 10-20             | 0.34            | 0.28             | 0.36            | 0.40               | -17.6               | 5.9                 | 17.6               |
| 20-30             | 0.21            | 0.18             | 0.24            | 0.32               | -14.3               | 14.3                | 52.4               |
The cultivation of perennial grasses for 5 years has a beneficial effect on the total nitrogen content in the layer of 0-50 cm of leached chernozem. The layer of 0-30 cm was characterized by an increase in the total nitrogen content from 0.18-0.30 to 0.24-0.36%, which exceeds the values of the arable land of 1968. In the layer of 30-50 cm, the increase was not so pronounced relative to 1968. In the layer of 0-30 cm of the fifteen-year grass fallow, the total nitrogen content increased to 0.32-0.40% - the excess is 14.3-52.4% relative to the arable land of 1968. Despite such a strong increase in the content of total nitrogen, the variant with the grass fallow cannot be compared with the values of virgin lands, where this indicator is 0.38-0.47%. A layer of 0-30 cm of leached chernozem in virgin land, arable land and grass fallow was characterized by low enrichment of humic substances with nitrogen, which is a feature of chernozems in Western Siberia (C: N = 11 -14 units). At the arable land of 1968, this indicator amounted to 11.2-13.0 units (table 4). Deeper than 30 cm, the ratio of carbon to nitrogen was significantly less - 2.5-5.0 units, which is explained by the lack of organic matter.

Table 5. Changes in the C:N ratio during the transition of old arable leached chernozem to grass fallow state.

| Sampling depth, cm | Arable land 1968 | Grass fallow 2008 | Virgin land 2008 | Deviation, % relative to arable land of 1968 |
|-------------------|------------------|------------------|------------------|-------------------------------------------|
| 0-10              | 12.6             | 12.6             | 11.1             | 7.1                                       |
|                   | 13.5             | 13.5             | 10.9             | -10.0                                     |
|                   | 12.6             | 12.6             | 9.7              | -26.8                                     |
|                   | 11.2             | 12.6             | 8.2              | -37.7                                     |
|                   | 5.3              | 6.3              | 3.7              | -12.5                                     |
| 40-50             | 4.4              | 4.1              | 3.7              | -6.8                                      |
| 50-60             | 4.1              | 4.1              | 3.7              | -4.1                                      |
| 60-70             | 3.2              | 3.3              | 3.1              | -12.5                                     |
| 70-80             | 2.5              | 2.7              | 2.4              | -8.0                                      |

Over the years of use of chernozem as arable land (25 years), the C:N ratio in the arable layer (0-30 cm) increased to 12.6-14.3 units - the deviation was 7.1-12.5% relative to the data of 1968. In the layer of 30-40 cm, nitrogen enrichment decreased by 37.7% relative to 1968 and amounted to 7.3 units. The fact of an increase in C:N confirms the deterioration in the humus quality and the depletion of chernozem during this period.
Transition to a grass fallow state allowed restoring the enrichment of humus with nitrogen to the values of 1968 for five years. In the layer of 0-30 cm, this ratio decreased to 9.7-12.6 units, which is 10.8-13.4% less than the initial values. A sharp decrease in the C:N ratio in the layer of 40-70 cm, in our opinion, is caused by the further migration of nitrogen-containing compounds deep into the soil, despite the absence of mechanical treatments during this period. The fifteen-year-old grass fallow is not inferior to the virgin lands of the leached chernozem by enrichment of humus with nitrogen. In a layer of 0-30 cm, C:N reaches 8.2-11.6 units.

**Conclusion**

Thus, the use of old arable leached chernozem as arable land during 25 years led to a decrease in the humus content in the layer of 0-30 cm from 7.6 to 6.9-7.0%. The loss of humus in the meter layer was 14 t/ha: in the layer of 0-30 cm, the decrease was equal to 18 t/ha (7.7% of the humus reserves), of which 4 tons migrated to deeper layers. The dehumification rate in the layer of 0-30 cm was 0.7 t/year (0.3% of humus reserves).

A five-year grass fallow made it possible to restore the humus state to the level of 1968 only in the layer of 0–20 cm — 7.2–7.4%. The rate of accumulation of humus was 1.9 t/year. At a depth of more than 30 cm, humus reserves decreased from 80 to 73 t/ha. After 15 years of growth of perennial herbaceous plants, the humus content in the layer of 0-20 cm increased to 7.5-8.0%, while on the virgin land - 8.3-9.0%. The humus reserves in the meter layer increased by 19.0 t/ha. The rate of humus accumulation in the layer of 0-30 cm is 1.7 t/ha. Transition to a grass fallow state allows restoring the enrichment of humus with nitrogen to the level of arable land of 1968 for five years. For 15 years, the ratio of carbon to nitrogen reaches the level of virgin land - 8.2-11.6 units.

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