Ecological differentiation of arable layers of leached chernozem and crop yields

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Abstract. The paper contains the materials of long-term research connected with studying the fertility inhomogeneity of the arable soil layer. The duration of cultivation, weather conditions, soil cultivation methods leave their imprint on the fertility of parts of the arable layer. It is revealed that effective fertility of the arable layer decreases from the top down, and the longer the nonmouldboard cultivation is used, the lower the fertility of lower layers. Plowing provides mixing of soil layers of the arable layer and creates a homogeneous layer by fertility, although the differentiation of the layers by their fertility exists even in case of plowing, but less pronounced. The maximum yield of spring wheat grain grown on the soil from different layers is observed in the variant from the 0-10 cm layer, and the minimum - in the variant from the 20-30 cm layer. Mixing of parts of the arable layer helps to smooth out and increase effective fertility of the root-inhabited soil. It is necessary to approach differentially when selecting a soil cultivation method and creating a fertile arable layer to obtain a high yield of cultivated plants.

1. Introduction

The main problem of the soil cultivation theory, which causes controversy, is the justification of the inversion of the arable soil layer. People have plowed up the arable soil layer since ancient times, and now this technique – plowing is being applied in most countries of the world. Today, there are disputes over nonmouldboard and mouldboard, surface and deep soil cultivation for annual cultivated plants [1-22].

The importance of preserving plant residues on the surface of arable land to protect soil from wind erosion and snow accumulation is well known and cannot be disputed, however, different approaches are adopted in science to the theoretical justification of nonmouldboard and mouldboard, surface and deep soil cultivation. Agronomical science has established that over the vegetative period, the arable soil layer is differentiated by fertility. Therefore, when the theoretical justification of soil cultivation systems in crop rotation fields is used, this phenomenon must be taken into account, especially when choosing technological operations: inversion, mixing, cultivation depth, etc. Meanwhile, it is known to agronomic science that the fertility differentiation of the arable soil layer was first discovered in Russia by V.I. Sazonov [15], and more detailed experimental studies to determine this process were carried out by A.N. Lebedyantsev [8], L.N. Barsukov, K.M. Zabavskaya [2], B.C. Franceson [3] and many other researchers on different types of soils and in different regions of the country. It must be said that all the above-mentioned authors come to the conclusion that the upper parts of the arable layer at the end of the vegetative period are more fertile than the lower parts, which is expressed in a
relatively larger content of nutrients, especially nitrogen and phosphorus, as well as in the nitrification activity. This phenomenon is also noted by other researchers [6,14,15,18].

Various applied soil cultivation systems - mouldboard, subsurface, combined – differently combine the physical, chemical and biological processes that take place in it, which results in the differentiation of layers by their fertility. Even in case of plowing, when a homogeneous arable layer is created, after a while, it is differentiated by fertility, and in case of nonmouldboard soil cultivation methods, when soil layers are not subjected to such thorough mixing and dilution with the organic matter mostly concentrated in the upper arable layers, the fertility differentiation of the layers is even more noticeable, as evidenced by the above results and the data of many researchers [10,16,17].

The degree of the fertility differentiation of the arable layer is determined by moisture, aeration, temperature, light and soil density, presence of nutrients for plants and, consequently, fertilization, the influence of plants on the soil, the activity of microorganisms [5,9,10,11,12,21].

2. Quality of soil from duration and method of use

The long-term application of soil subsurface cultivation, which is used in many regions of the country, can contribute to the fertility differentiation of soil layers, and A.V. Tikhonov and S.M. Svitko [20] believe that the long-term application of the mouldboard cultivation provides more efficient fertility than subsurface cultivation and surface tillage.

In order to check it, a laboratory-field experiment was conducted on leached chernozem, which was established annually in fourfold repetition. Spring wheat was sown in 50x50x30 cm lysimetric boxes, 100 seeds in each. The results are presented in Table 1.

| Soil layer | Unit of measurement | Continuous mouldboard cultivation | Subsurface cultivation (nonmouldboard) |
|------------|---------------------|------------------------------------|---------------------------------------|
|            |                     | 3 years | 4 years | 5 years |
| 0-10       | t/ha                | 6,35    | 7,66    | 5,74    | 5,50    |
|            | %                   | 100     | 100     | 100     | 100     |
| 10-20      | t/ha                | 6,58    | 6,56    | 4,77    | 4,43    |
|            | %                   | 93,7    | 85,6    | 83,1    | 80,7    |
| 20-30      | t/ha                | 5,94    | 6,07    | 2,94    | 2,99    |
|            | %                   | 88,0    | 72,9    | 51,2    | 54,3    |
| 0-30       | t/ha                | 6,85    | 7,10    | 5,27    | 4,94    |
|            | %                   | 102,0   | 92,6    | 91,7    | 89,1    |
| LSD<sub>05</sub> | t/ha | 0,34 | 0,25 | 0,18 | 0,33 |

When the crop was recorded, the yield of spring wheat grown on the soil from the 0-10 cm layer was taken for 100%. According to the results obtained, the yield of spring wheat during the observations using subsurface cultivation, grown on the soil in the variant of the 10-20 cm layer was 15-20% lower, and from the 20-30 cm layer - 27-49% lower than that from the 0-10 cm layer. In the variant of continuous mouldboard cultivation, there was also a differentiation of the soil layers by their fertility, but it was manifested much less.

As it is known, effective fertility is mainly realized through the activity of soil microorganisms [6,14,23]. Most of the useful microorganisms involved in the most important transformations of the organic matter in soil are aerobes. Periodic inversion of soil leads to mixing of its layers, which contributes to an increase in effective fertility [7,19]. Consequently, periodic soil inversion can regulate the microbiological activity in soil and the accumulation of available nutrients.

However, annual inversion of the plow layer is not necessary for this purpose. According to the data in Table 1, the fertility of the upper layers (0-10 and 10-20 cm) after a three-year use of
subsurface cultivation, as compared to continuous plowing, did not decrease, and of the upper 0-10 cm layer was even higher. The yield of wheat grown on the soil from the 0-10 cm layer after a three-year use of subsurface cultivation was 7.66 t/ha, and with continuous plowing - 6.35. According to the research results, it was also revealed that the use of annual subsurface soil cultivation for more than three years leads to a 45-50% decrease in the fertility of the 20-30 cm layer.

Thus, based on our experiments and the literature data, it can be concluded that annual subsurface cultivation of leached chernozem results in some deterioration in the biological properties of soil and a decrease in effective fertility in the lower part of the cultivated layer. Periodic inversion of soil in the crop rotation contributes to an increase in its effective fertility.

3. Fertility and productivity
An important theoretical position on the fertility differentiation of the arable layer was discovered by Russian scientists in the early 20th century. They established that if the arable layer is not trenched, the fertility due to the influence of atmospheric precipitation, figuratively speaking, is pulled into the upper layer. The practical significance of this discovery was first shown by L.N. Barsukov [2].

In order to study various aspects of this phenomenon, over a number of years we established field and laboratory-field experiments at different times on leached chernozem. We dug 50x50x30 cm lysimetric boxes with an area of 0.25 m² at the experiment sites with three repetitions, and filled them with soil according to the schemes and objectives of the studies, and sowed 100 seeds of the culture in each box (at the rate of 4 million of viable seeds per 1 hectare).

To study the dynamics of the fertility differentiation of soil layers in the course of time, and depending on climatic conditions, in 1989, an experiment was established on leached chernozem according to the scheme:
1. Soil from the 0-10 cm layer;
2. Soil from the 10-20 cm layer;
3. Mixed soil from the 0-10 and 10-20 cm layers;
4. Soil with unbroken, natural consistency (control).

The 1989 experiment establishment was used to sow barley and study the dynamics of the fertility differentiation of the arable layer over the next three years. In 1990 a new establishment was made, alongside with the old one. The harvest data was processed mathematically. The results of the surveys and observations are presented in Table 2.

The climatic conditions in the years of the experiments were not identical. The year of the experiment was preceded by relatively dry years of 1987, 1988. Due to the lack of moisture, organic matter of the soil, especially in the upper layers, almost did not decompose and was not supplied to the 10-20 cm layer. Therefore, in 1989, the highest barley yield of 3.02 t/ha was observed in the variant where barley was grown in the soil from the 0-10 cm layer. It was 343% in relation to the variant with unbroken soil consistency. The variant with mixed soil from the 0-20 cm layer occupied an intermediate position by the barley yield (1.27 t/ha) among the remaining two variants. That is, dry years contributed to the increase in the fertility difference of various parts of the arable layer, especially the upper one in relation to the other layers. Our data overlap with the results of other researchers [5; 10].

Over time, the stratification of the layers by their fertility relative to the control variant (unbroken consistency) gradually weakens, as evidenced by the data of 1991. That is, over the third year, if the soil is not trenched, although the layers are differentiated by their fertility, the fertility of the layers is leveled and approaches the soil fertility of the variant with unbroken profile consistency. This indicates that soil microorganisms "making themselves at home after the shock - displacement, mixing, etc." begin to work in the usual mode, as in natural conditions. It is proved by the biological activity of soil determined by the linen canvas method.

Thus, for example, in 1989, the degree of decomposition of the linen canvas in the soil in the 0-10 cm variant was 59.8%, in the variant with the 10-20 cm layer - 34.0%. In the variant, where the soil was mixed (0-20 cm), it was 36.0%, and in the variant with unbroken, natural soil consistency -
35.7%. In 1991 (the establishment of 1989), it was within the range of 58.8-61.3% in all the variants of the experiment, i.e. rather high, with the values close to the first variant.

**Table 2.** Barley yield depending on the fertility of the soil layers, the time of the experiment establishment and the weather conditions of the years under study, t/ha, %.

| Experiment variants | Grain of 1989 experiment | Herbage | Grain of 1990 experiment | Herbage |
|---------------------|--------------------------|---------|--------------------------|---------|
|                     | t/ha | % | t/ha | % | t/ha | % | t/ha | % |
| 0-10                | 3,02 | 343 | 3,71 | 174 | 12,86 | 104.4 | 3,40 | 163 |
| 10-20               | 0,81 | 92  | 3,41 | 160 | 12,31 | 100  | 2,91 | 140 |
| 0-20                | 1,27 | 144 | 1,90 | 89  | 11,98 | 97   | 2,87 | 138 |
| Unbroken consistency | 0,88 | 100 | 2,13 | 100 | 12,32 | 100  | 2,08 | 100 |
| LSD05               | 0,136 | 0,204 | 0,828 | 0,204 |

Precipitation over the year, mm: 442 597 491 597
Precipitation over May-August, mm: 166 289 161 289

In 1999, in order to assess the fertility of deeper parts of the arable layer, we established a laboratory-field experiment according to the aforesaid method. We added variants with mixed soil from the 0-30 cm layer and a variant with soil from the 20-30 cm layer. The yield of barley grown on the soil from the 0-10 cm layer was taken for 100%, the results of the experiment are presented in Table 3.

**Table 3.** Yield of barley grown on soil from various parts of the arable chernozem layer in 1999-2000, t/ha.

| Experiment variants | 1999 | 2000 | Average yield over 2000 | 1999-2000 |
|---------------------|------|------|-------------------------|-----------|
|                     | Establishment of 1999 | Establishment of 2000 | y/ha | % |          |
| 0-10                | 6,11 | 5,59 | 4,22 | 5,30 | 100,0 |
| 10-20               | 4,75 | 3,70 | 3,33 | 3,92 | 74,0  |
| 20-30               | 4,07 | 3,55 | 2,92 | 3,52 | 66,3  |
| 0-30 “mixed”        | 4,88 | 3,58 | 3,16 | 3,87 | 73,0  |
| Unbroken consistency| 5,87 | 3,53 | 3,11 | 4,17 | 78,6  |
| LSD05               | 0,18 | 0,49 | 0,49 | 0,39 | 7,4   |

Over the vegetative season in 1999 and 2000, 311 mm of precipitation fell out at an average annual value of 235 mm, and over one year - 599 and 677 mm, respectively (mean annual - 423 mm), i.e. in general, the years are characterized as wet.

According to the results of the experiment, over 1999-2000, the fertility of the top 0-10 cm soil layer, as compared to other variants, expressed through the barley yield, was at the average 1.13-1.78
t/ha or 21.4-33.7% higher than in other variants. These results allow us to conclude that the effective fertility of the arable layer largely depends on the fertility of the upper 0-10 cm soil layer, where the main biomass of plant residues and soil microorganisms is concentrated.

In 2008, we established a laboratory-field experiment with Odessky barley in the forest-steppe zone on leached chernozem with the 5% humus content to study the structure of the crop and the yield of barley grown on the soil from various parts of the arable layer. The soil was taken from a site where fertilizers, herbicides and other chemicals were never used. Lysimetric boxes were filled with soil with three replications according to the scheme:

1. Soil representing a carefully mixed mixture of 0-10, 10-20 and 20-30 cm layers;
2. Soil from the 0-10 cm layer;
3. Soil from the 10-20 cm layer;
4. Soil from the 20-30 cm layer;
5. Soil with unbroken layer consistency (not mixed).

100 barley seeds were sown in each box (area – 0.25 m²) using a stencil. The 2008 experience was used to sow barley in 2009. Barley was re-sown in the loosened soil to the depth of seed placement in the boxes. In addition, in 2009, we made a new laying using the same scheme as in 2008.

Table 4 shows the biomass and the structure of the barley yield in the years under study. The minimum biomass of a sheaf by the experiment variants over two years of observations was noted in the variant with the 20-30 cm layer. Lower values of this indicator were noted in the arid year of 2008.

### Table 4. Structure of the yield of barley grown on the soil from different layers.

| Experiment variant, Soil layer | Biomass of a sheaf from 1 m², g | Number of grains in a head, pcs. | Weight of the grain from 10 heads, g | Weight of a the grain from a sheaf from 1 m², g |
|-------------------------------|---------------------------------|---------------------------------|-----------------------------------|-----------------------------------------------|
| 0-30 “mixed”                  | 1470.8±37.6*                   | 18.57±2.28                      | 7.34±0.36                         | 88.8±7.94                                      |
| 0-10 cm                       | 1498.8±16.44                   | 18.87±2.72                      | 8.79±0.80                         | 106.8±10.24                                    |
| 10-20 cm                      | 1486.8±14.19                   | 18.97±1.42                      | 7.23±0.37                         | 86.8±4.15                                      |
| 20-30 cm                      | 1382.8±17.21                   | 18.27±3.39                      | 6.20±0.48                         | 74.4±5.44                                      |
| 0-30 “unbroken”               | 1474.8±18.9                    | 18.93±6.8                       | 9.14±1.23                         | 109.7±4.18                                     |
| 0-10                          | 2018.8±11.0                    | 21.0±2.92                       | 10.3±0.55                         | 132.4±3.78                                     |
| 10-20                         | 1870.8±17.2                    | 18.9±2.96                       | 9.39±0.59                         | 112.7±3.98                                     |
| 20-30                         | 1012.0±17.1                    | 18.3±2.95                       | 8.5±0.96                          | 102.1±5.24                                     |
| 0-30 “mixed”                  | 2057.2±27.7                    | 22.17±2.73                      | 9.29±2.66                         | 111.5±9.95                                     |
| 0-10                          | 2113.2±25.15                   | 20.60±2.16                      | 9.83±0.52                         | 118.0±5.51                                     |
| 10-20                         | 2049.2±20.55                   | 19.73±2.79                      | 9.30±1.05                         | 111.6±5.66                                     |
| 20-30                         | 2005.2±16.44                   | 19.23±2.33                      | 9.06±2.14                         | 88.7±7.36                                      |

*Note: ± – mean-square deviation according to A.K. Guminsky [4].

In the variant with the 0-10 cm layer, all the parameters of the barley yield structure, as well as the biomass of the sheaf, were higher, as compared to other variants, especially in the wet year of 2009.

If we take the weight of the grain from the sheaf in the 0-10 cm variant in 2008 for 100% (106.8 g/m², laying of 2008), in 2009 (laying of 2008), it will amount to 124% (132.4 g/m²), and in 2009 (laying of 2009) - 110.5% (118.0 g/m²). That is, the more favorable the conditions for the growth and development of the culture, the higher its yield.

Over the years of observation, the maximum grain yield and the indicators of the barley yield structure were noted in the variant with the 0-10 cm soil layer, and the minimum - in the 20-30 cm layer. This allows us to conclude that effective soil fertility decreases in the plowing
layer down the profile. Mixing of parts of the arable layer helps to smooth out and increase the soil fertility.

4. Conclusion
Over the years of observation, the maximum grain yield and the indicators of the barley yield structure were noted in the variant with the 0-10 cm soil layer, and the minimum - in the 20-30 cm layer. This allows us to conclude that effective soil fertility decreases in the plowing layer down the profile. Mixing of parts of the arable layer helps to smooth out and increase the soil fertility. Studying the problem of the differentiation of the arable layer by fertility is of great scientific and practical importance, since it becomes the theoretical basis for recommendations on soil cultivation in general.

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