Spatial variability of the content of labile humus substances in black soils and their relationship with microbial biomass

A G Kaluzhskikh, A G Belyaev and M A Zaikina
Kursk State South-Western University, 94, 50 years Oktyabrya Street, 305040, Kursk
E-mail: alex-kaluzhskih@yandex.ru

Abstract. The content of labile humic substances was studied in typical black soils, permanent fallow and arable lands depending on the relief and agrogenic factors. Their spatial variability was estimated. The correlation analysis identified a direct correlation between the content of labile humic substances in typical black soils and microbial biomasses. The need for post-harvest residues and organic fertilizers was identified.

1. Introduction

One of the main tasks of modern agriculture is to preserve the ecological role, stable and sustainable soil performance [1].

Under the conditions of intensified agriculture, the anthropogenic impact on the soil and its fertility increases which causes its degradation, deteriorates its fertility and productivity. An important indicator of soil fertility is the content of labile humic substances (LHS) which are the most transformable part of humus increasing the crop yield. Currently, climate changes increase plant productivity which can produce a significant amount of exogenous carbon in cultivated soils [4].

The amount of organic carbon depends on the biological participation of the soil in crop growth. The decomposition, transformation and stabilization of organic substances is an indicator of soil activity [2].

Many researchers argue that microorganisms play a key role in the biotransformation of organic substances [3].

LHSs are part of organic soil substances which are an energy material for microorganisms, a “buffer” between the living population and the relatively stable part of humus, a reserve for nitrogen production. From agronomic and ecological points of view, the labile part of humic substances is very important. In the system of humus substances of chernozem, the most transformable fraction is labile humus substances extracted from fresh soil or soil composted at optimum humidity and soil temperatures (60% of the total moisture capacity of the soil and +26-28°C). These include young forms of humus which are loosely bound to the mineral part of the soil and enriched with nitrogen. [9, 12].

One more important component of the active part of organic substances of chernozem is the microbial biomass which transforms the most important nutrients.

However, the effect of agrogenic factors and the slope exposure on the content and spatial variability of LGV, its relationship with the microbial biomass are understudied, despite their role in controlling soil fertility, increasing crop yields and developing a humus monitoring system. Therefore, the study of the spatial variability of LHS content in typical chernozem depending on the location in relief, agrogenic factors and their relationship with the microbial biomass is relevant.
2. Materials and methods
The multifactorial field stationary experiment (MFSE) was conducted in 2006-2009 in the All-Russian Research Institute of land studies and soil protection founded in 1984. The land plot was four grain-fallow (fallow - winter wheat - maize - barley) and grain grass (clover - clover - winter wheat - barley) fields located on the watershed plateau and the slopes of northern and southern exposures. The methods of soil and subsoil tillage were used. The experiment was also conducted in the steep steppes and on the permanent 60-year-old black fallow in the Central Black Earth Biosphere Reserve n.a. V.V. Alekhin (Kursk region, Medvensky district). Soil and subsoil tillage methods were used for a depth of 25-27 cm for maize and 20-22 cm for other plants.

The MFP soil is a typical heavy loamy chernozem formed on forest-type deposits. The humus content in the topsoil is average. It varies from 4.72% on the southern slope to 5.38% and 5.60% on the northern slope and the fissure plateau.

The soil of the Central Black Earth Biosphere Reserve n.a. V.V. Alekhin is typical black heavy loamy chernozem formed on forest-like deposits. The humus content in the 0–20 cm soil layer is 10.82 ± 0.17%, in the permanent fallow, it is 3.95 ± 0.06% [7].

The following variants were used to study the spatial variability of labile humus substances in the black soil: 1) without fertilizers, soil tillage, 2) without fertilizers, subsoil tillage; on the permanent 60-year-old fallow, soil samples were taken on an area of 90 m2 in grid points 2.5 × 6 m (n = 12) with a drill at depths of 0-10, 10-20 cm.

In soil samples, labile humic substances and their composition were determined in a 0.1N NaOH extract according to the methodology of the Soil Institute (1983) with preliminary composting [10]; the biomass of microorganisms was determined using the rehydration method [5]. The obtained data were processed using the methods of mathematical statistics [8].

3. Results and its discussion
The studies have shown that in the incalculable steppe, the LHS content in the 0–10 cm layer varied from 9,590 mg/kg of soil to 13,860 mg/kg of soil; the level of spatial variability was low, the coefficient of variation was 11% (Table 1). In the soil layer of 10–20 cm, the LHS content varied from 5110 to 11640 mg/kg of soil, the spatial variation of the parameter was average. It was higher than in the upper layer (24%).

| Humic substances | Soil layer, cm | Arithmetic average, mg/kg | Standard deviation, mg/kg | The coefficient of variation, % |
|------------------|----------------|---------------------------|--------------------------|-------------------------------|
|                  | Unmowed steppe |                           |                          |                               |
| Labile humic substances | 0-10          | 11731                     | 1340                     | 11                            |
|                   | 10-20          | 8592                      | 2027                     | 24                            |
|                  | Permanent fallow |                         |                          |                               |
| Labile humic substances | 0-10          | 5458                      | 554                      | 10                            |
|                   | 10-20          | 5237                      | 549                      | 10                            |

The amount of LHS in the 0–10 cm chernozem in the unmowed steppes is 1.3 times more than in the 10–20 cm layer. This may be due to a large number of organic residues concentrated in the upper soil layer.

In the permanent fallow, where the soil is annually treated, the content of LHS decreased 2.1 times as compared with the virgin soil. In the 0-10 cm layer, it varied from 4574 mg/kg of soil to 6570 mg/kg of soil; in the 10-20 cm layer, it varied from 4408 mg/kg to 6376 mg/kg. Differences in the content of labile humic substances between the 0-10 and 10-20 cm soil layers are not significant at P = 95%, and the spatial variation was 10%. This can be caused by constant mixing during tillage in the absence of
plant residues which levels the amount of labile humic substances between the typical black soil layers (Table 1). According to Stakhurlova, Svistova, and Shcheglov [13], in arable lands, intensified decomposition of organic substances is followed by exhaustion of its reserves and decomposition of mobile humic substances which reduces potential and effective soil fertility.

The effect of slope exposures on the content of labile humic substances in typical chernozem was revealed (Table 2). On the slope of northern exposure in grain-fallow crop rotation with soil tillage, in the 0-10 cm layer, the LHS content was 2.3 times higher than on the southern slope. In the 10-20 cm layer, similar patterns were observed. The content of labile humic substances in the soil of the northern slope is less than on the watershed plateau. The level of spatial LHS variability on arable lands is low and does not depend on exposures: the coefficients of variation are 4–9% and 5–9%.

Table 2. Spatial variability of the content of labile humic substances in typical black soils in the grain-crop rotation depending on the slope exposure and tillage system

| Slope               | Tillage          | Soil layer, cm | Arithmetic average, mg/kg soil | Standard deviation, mg/kg | The coefficient of variation, % |
|---------------------|------------------|----------------|--------------------------------|---------------------------|--------------------------------|
| Watershed plateau   | Subsoil          | 0-10           | 4777                           | 299                       | 6                              |
|                     | Subsoil          | 10-20          | 4581                           | 406                       | 9                              |
| North               | Soil tillage     | 0-10           | 4427                           | 385                       | 9                              |
|                     |                  | 10-20          | 4276                           | 336                       | 8                              |
| South               |                  | 0-10           | 1902                           | 84                        | 4                              |
|                     |                  | 10-20          | 1794                           | 101                       | 6                              |
| Multi-factor field  |                  |                |                                |                           |                                |
| experiment, grain-fallow crop rotation, barley | | | | | |
| South               |                  | 0-10           | 4738                           | 364                       | 8                              |
|                     |                  | 10-20          | 4394                           | 321                       | 7                              |
| Watershed plateau   | Subsoil          | 0-10           | 5595                           | 374                       | 7                              |
|                     |                  | 10-20          | 4898                           | 544                       | 11                             |
| Multi-field field   |                  |                |                                |                           |                                |
| experiment, grain/fallow crop rotation, pure fallow | | | | | |
| North               | soil tillage     | 0-10           | 2243                           | 102                       | 5                              |
|                     |                  | 10-20          | 2085                           | 119                       | 6                              |
| South               | soil tillage     | 0-10           | 2339                           | 214                       | 9                              |
|                     |                  | 10-20          | 1910                           | 136                       | 7                              |
| Watershed plateau   | soil tillage     | 0-10           | 5056                           | 501                       | 10                             |
|                     |                  | 10-20          | 4832                           | 502                       | 10                             |
| Subsoil             |                  | 0-10           | 5470                           | 244                       | 4                              |
|                     |                  | 10-20          | 5261                           | 248                       | 5                              |

Note: LHS - labile humic substances.

The effect of tillage on the content and spatial variability of labile humic substances in typical chernozem was found in a grain-fallow crop rotation. For the subsoil tillage in layers of 0–10, 10–20 cm, the content of LHS was higher regardless of the exposure. An exception is the soil layer of 10-20 cm on the southern slope, where the content of LHS is characterized by a reverse trend. The level of spatial variation of LHS is low and approximately the same on the exposures under study for all tillage methods. It has been established that under soil tillage, the spatial variation of LHS is twice as high as that under subsoil tillage (10% and 5%, respectively). However, they are in one low gradation.

The content of labile humic substances in the soil varies by year, depending on the type of crop in the crop rotation. Thus, in the pure fallow in the grain-fallow crop rotation under soil tillage, there was a tendency to a higher content of LHS in chernozem than in barley crops (Table 2). This can be explained by more favorable weather conditions for humification of plant residues in July 2007: the average air
temperature and the amount of precipitation were higher (pure fallow, + 20 °C, 60 mm) than in 2006 (barley, + 18.5 °C, 42 mm). Moreover, it can be explained by a large number of organic residues that entered the soil after harvesting.

During transformations of soil organic substances, its mineralization and humification, microorganisms play an important role [11]. V.M. Volodin, N.P. Masyutenko, and V.F. Yurinskaya [6] identified the relationship between the content of mobile humic substances and indicators of biological activity of the typical black soil under different tillage systems.

The correlation analysis allowed us to estimate the degree of connection between microbial biomass (MB) and the content of labile humus substances depending on natural and agrogenic factors. A direct link between microbial biomass and soil humus substances was established. The degree of relationship and its orientation depends on the slope exposure, the research period, the type of crop rotation and the soil layer. A strong relationship was observed on the southern slope during the growing (May-June) and harvesting (August) seasons, as well as on the northern slope in July and August (Table 3).

**Table 3.** Assessment of the relationship between microbial biomass and the content and composition of labile humic substances and humus in the arable layer of typical black soils depending on the duration of studies, exposure and crop rotation

| Exposure        | Crop rotation | Correlation coefficient, *r* | May | June | July | August |
|-----------------|---------------|-------------------------------|-----|------|------|--------|
|                 |               |                               | LHS | H    | LHS  | H     |
| South           | GFCR          | 0.78                          | 0.91| 0.76 | 0.87 | 0.44  |
|                 | GGCGR         | 0.98                          | 0.97| -    | -    | 0.37  |
| North           | GFCR          | 0.16                          | 0.10| 0.46 | 0.88 | 0.88  |
|                 | GGCGR         | 0.70                          | 0.88| 0.34 | 0.78 | 0.42  |
| Watershed plateau | GFCR       | 0.45                          | 0.41| 0.12 | 0.92 | 0.85  |
|                 | GGCGR         | 0.12                          | 0.25| 0.57 | 0.47 | 0.92  |

*Note:* LHS - labile humic substances; H - humus; GFCR - grain fallow crop rotation; GGCGR - grain grass crop rotation.

In May and August, on the southern and northern slopes and the watershed plateau, the relationship between MB and humus was very strong; the correlation coefficient was 0.8-0.9 and 0.7-0.8, respectively. In July, the correlation coefficient was high. In subsequent years, the revealed pattern was confirmed both under soil and subsoil tillage systems. This pattern was confirmed by the coincidence of direction and nature of the dynamics of MB and labile humus substances in typical black soil.

Thus, the agricultural use of typical chernozem in the grain-fallow crop rotation reduces the content of labile humic substances 1.6-6.5 times compared to the virgin soil depending on the slope exposure, agrogenic factors and soil layer. On the other hand. There is a tendency to reduce the variability of these indicators and differentiation of 0-10 cm and 10-20 cm soil layers. A sharp decrease in the amount of labile humic substances is due to the lack of organic substances and mineralization of labile humic substances in the process of growing crops, as they are the closest source of nutrients. Labile humic substances are products of transformation of fresh organic substances. Therefore, to maintain their content at a proper level, it is necessary to ensure that a sufficient amount of post-harvest residues and organic fertilizers enter the soil [10]. Uniformity of the upper layer of typical chernozem is due to anthropogenic effects.

With prolonged fallowing, in the absence of fresh organic substances in typical chernozem, a decrease in the content of labile humic substances (unmowed steppe), the degree of their spatial variation, and the difference in their content between 0-10 and 10-20 cm layers were observed. However, the level of labile humus substances observed in the permanent fallow is due to the
decomposition of inert humus with intensive mechanical action on the soil. Therefore, with long-term permanent fallowing, the content of humus is 3.95 ± 0.06 [7].

4. Conclusions
It has been established that the soils of the northern slope are enriched with labile humus as compared with the southern one. On the northern slope, a 0-10 cm layer of typical chernozem contains 2.3 times more LHS. In the 10-20 cm layer, a similar pattern was observed. The subsoil tillage increases the amount of labile humic substances in the soil. Tillage methods have an ambiguous effect on the spatial variation of LHS. Under subsoil tillage, there is a slight increase in the spatial variation of humus lability on northern and southern slopes and a decrease – on the watershed plateau. The lability of humus decreases on the southern slope 2.2-3.3 times.

A close direct relationship between the microbial biomass and humus substances during various periods of active plant vegetation and harvesting was established. In the post-harvest period, the relationship of microbial biomass with humus weakens on the northern slope and the watershed plateau in the grain-fallow and grain-grass crop rotations.

The results of studies of environmentally and agronomically important labile components of humic substances are crucial for developing soil fertility management systems in order to increase their productivity, as well as for developing a system for monitoring the content of labile humus substances in black soils.

References
[1] Skuodienė R, Karčauskienė D, Repšienė R 2016 The influence of primary soil tillage, deep loosening and organic fertilizers on weed incidence in crops Zemdirbyste – Agriculture 103(2) 135–142
[2] Shixiu Zhang, Neil B. McLaughlinb, Shuyan Cui, Xueming Yang, Ping Liu, Donghui Wu, Aizhen Liang 2019 Effects of long-term tillage on carbon partitioning of nematode metabolism in a Black soil of Northeast China. Applied Soil Ecology. 138 207–212
[3] Zhechao Zhang, Yue Zhao, Ruoxi Wang, Qian Lu, Junqiu Wu, Duoying Zhang, Zhuanfangie, Zimin Wei 2018 Effect of addition of exogenous precursors on humic substance formation during composting. Weste Management. 79 462–471
[4] Zhiyuan Zhang, Wang W, Qi J, Zhang H, Tao F, Zhang R 2019 Priming effects of soil organic matter decomposition with addition of different carbon substrates. J. of Soils and Sediments, 19 1171–1178
[5] Blagodatsky S A, Blagodatskaya E V, Gorbenko A Yu, Panikov N A 1987 Rehydration method for determining the biomass of microorganisms in the soil. Pedology. 4 64–71
[6] Volodin V M 1988 Changes in the composition of humic substances and the biological activity of eroded chernozems with minimal processing Bulletin of agricultural science. 2 55–59
[7] Glazunov G P 2009 Active pool of organic matter of typical chernozem and its connection with the yield of grain crops Dissertation, Kursk
[8] Dospékov B A 1985 Methods of field experience (with the basics of statistical processing of research results) (Moscow: Agropromizdat) 351 p.
[9] Kogut B M 2003 Principles and methods for assessing the content of transformed organic matter in arable soils Soil Science. 3 308–316
[10] Masyutenko N P 2012 Transformation of organic matter in black earth soils of the Central Black Earth Region and its reproduction system (Moscow: Russian Agricultural Academy) 150 p.
[11] Parinkina O M 1995 Microbiological Aspects of the Reduction of Natural Soil Fertility in Their Agricultural Use Soil Science 5 573–581
[12] Recommendations for the study of the balance and transformation of organic matter in agricultural use and intensive soil cultivation (VASHNIL. Soil Institute named after V.V. Dokuchaev: Moscow) 1984 96 p.
[13] Stakhurlova L D, Svistova I D, Shcheglov D I 2007 Biological activity, as an indicator of chernozem fertility in various biocenoses *Soil Science* 6 769–774