Dependence of winter wheat yield on the content and composition of organic matter of typical chernozem

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Abstract. The article is devoted to the study of the relationship and the determination of the dependence of winter wheat yield on the content and composition of the organic matter of typical chernozem, the determination of its optimal parameters in different by hydrothermal conditions years. The research was carried out in 2018-2019 in a typical heavy-loamy chernozem in the experimental field of the Kursk FARC. Coupled studies of the yield of winter wheat Synthetics and indicators of soil organic matter in the topsoil were carried out on 30-meter sites during the harvest period. The range of fluctuations in the content and composition of organic matter in the soil, the yield of winter wheat at the studied sites allowed us to apply information and logical analysis within the framework of the analyzed soil-plant system. A high dependence of winter wheat yield on the content and composition of soil organic matter was established, in 2018 the coefficients of information transfer efficiency varied from 0.23 to 0.17, in 2019 from 0.32 to 0.18. It was found that in dry 2019 the dependence of winter wheat yield on the biogenicity of mobile humus substances, the lability of humus, and microbial biomass has increased, and the influence of humus has decreased. It is established that in the studied years the significance of the parameters for the formation of winter wheat yield remained, the degree of their influence and sometimes the nature of the direction of the relationship changed. The optimal parameters of indicators of soil organic matter in the arable layer of chernozem typical for obtaining the yield of winter wheat Synthetic 5.45-7.24 t/ha in a favorable by hydrothermal conditions year and 4.78-7.19 t/ha in a dry year were established.

Key words: winter wheat, yield, relationship, humus, mobile humus substances, microbial biomass, typical chernozem, optimal parameters.

1 Introduction

One of the main factors that ensure a high yield of crops is soil fertility. In chernozem soils the determining role in soil fertility belongs to soil organic matter, which forms and maintains the properties, main functions and modes of the soil [1,2]. Under the conditions of constantly increasing potential crop yields soil organic matter is an important factor in obtaining a high and stable yield. It is a producer of CO₂ involved in photosynthesis, a source of macro- and microelements, determines agrophysical and biological properties of the soil that affect the growth, development and nutrition of plants. Therefore, it is important to study the relationship of crop yields with the content and especially with the composition and quality of soil organic matter. The research conducted in this direction is not sufficient [3-5]. Such research is necessary, on the one hand, to predict the yield of crops, on the other hand, to assess the content and composition of soil organic matter in order to develop a system for its regulation. To do this, it is necessary not only to assess the relationship between crop yields and the content and composition of soil organic matter, but also to determine its optimal parameters. One can solve this problem by using information and logic analysis.

The purpose of this work is to study the relationship between the yield of winter wheat and the content and

composition of the organic matter of typical chernozem and to determine its optimal parameters.

2 Materials and methods

The research was carried out in the experimental field of Kursk FARC (Kursk Region, Medvensky District, Panino village), located on the near-watershed area, in the field of winter wheat Synthetic crops. The soil is a typical heavy loamy chernozem on a carbonate loess-like loam. Three weeks before the harvest of winter wheat in 2018-2019, 30 meter-size sites (one-meter size sites) were planned so that the plants on them differed in height, density, etc. During the harvest period, the plants were cut from each meter-size site, weighed, sheaves threshed, and in the arable layer, a mixed soil sample (30 samples in total) was taken from 3 points on them. The humus content in soil samples was determined by Tyurin method in the modified by B. N. Nikitin with the spectrophotometric termination according to D.S. Orlov and N.M. Grindel [6]; the content and composition of mobile humus substances were determined in 0.1 n NaOH extract from the soil without decalcification in the modification of V.V. Dokuchaev Soil Institute with preliminary composting (VNIIZiZPE); the carbon content of microbial biomass in fresh soil samples was determined

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by the rehydration method [7], and the soil moisture was determined by the thermostatic-weight method.

In the topsoil (0-20 cm) of typical chernozem, the supply of typical chernozem with exchangeable potassium ranged from high (98 mg/kg of soil according to Chirikov method) to high (180 mg/kg of soil), mobile phosphorus varied from high (132 mg/kg of soil according to e Chirikov method) to very high (219 mg/kg of soil), alkaline hydrolyzable nitrogen (according to Cornfield method) from low (141 mg/kg of soil) to medium (164 kg/100 g of soil). The content of exchangeable calcium and magnesium varied from 20.6 to 22.2 and from 4.1 to 5.4 mg*eq/100 g of soil, respectively. The reaction of the soil solution in the arable layer is slightly acidic and close to neutral ($\text{pH}_{\text{H}_2\text{O}}$ 6.1-6.5).

The climatic conditions in the years of winter wheat cultivation in 2017-2018 and 2018-2019 were different. In 2018-2019, there were less favorable meteorological conditions for the formation of winter wheat yields than in 2017-2018.

The obtained experimental data were processed by methods of mathematical statistics and information-logical analysis [8] using software tools Microsoft office EXCEL, STATISTIKA, STATGRAF. Information and logical analysis allows us to identify and quantify the strength, nature, and direction of the relationship between the yield of crops and indicators of soil fertility, to determine their parameters specific to certain levels of yields.

3 Results and Discussion

The dependence of winter wheat yield on the content and composition of the organic matter of typical chernozem is studied on the basis of information and logical analysis: the content of humus (H), mobile humus substances (MHS), their quality (Cmha/Cmfa) and biogenicity (Cmb/Cmhs), mobile humic acids (MHA), mobile fulvic acids (MFA), carbon of microbial biomass (CMB), lability of humus (Cmhs/Ch).

In 2018-2019, when studying the indicators of the humus state of typical chernozem and the yield of winter wheat at the studied sites, the humus content in the arable layer varied slightly from 5.19 to 5.69 %, the coefficient of variation was 2.3 %. The amount of carbon of mobile humic substances in the studied soil layer varied from 4,160 to 6,390 mg/kg of soil, carbon of mobile humic acids from 2,278 to 3,400 mg/kg of soil, carbon of mobile fulvic acids-from 1,890 to 3,910 mg/kg of soil. At the same time, the variability of the first two indicators was average, the coefficients of variation (r), respectively, were 13.1 %; 10.9%, and the carbon content of mobile fulvic acids was significant (the coefficient of variation was 20.4 %). The average degree of variation of the quality index of mobile humic substances (the ratio of carbon of mobile humic acids to carbon of mobile fulvic acids) in the arable layer of the studied sites (the coefficient of variation -17.6 %) from 0.7 to 1.4. The degree of change in the lability of humus (the ratio of carbon of mobile humic acids to carbon of humus) in the arable layer is average ($r=12.8\%$) from 12.8 to 22.5%. The

carbon content of microbial biomass varied from 4,170 to 7,160 mg/kg of soil (coefficient of variation is 13.2 %).

The variation in winter wheat yield at the study sites was significant: in 2018 the coefficient of variation was 29.1 %, and its values varied from 1.94 to 7.24 t/ha; in 2019, the coefficient of variation was 29.3 %, and its values varied from 1.81 to 7.19 t/ha.

The range of fluctuations in the content and composition of organic matter in typical chernozem at the studied sites, as well as the yield of winter wheat, allowed us to rank them, build relationship channels between them and determine the uncertainty, informativeness, the amount of information transmitted (T) (Fig.1), the coefficient of information transmission efficiency (K) (Fig.2,3), i.e. to conduct an information-logical analysis. The values of winter wheat yield and the studied indicators of soil organic matter were divided into three classes (ranks).

It was found that under different hydrothermal conditions the amount of information transmitted from the indicators of soil organic matter to the yield of winter wheat is different (Fig. 1). In 2018 characterized in the spring-summer period by optimal moisture content of the territory ($\text{HTC}=1.31$) and increased heat, the greatest amount of information on the yield of winter wheat came from the following indicators of soil organic matter: the content of humus in the soil, mobile humus substances, mobile fulvic acids, the indicator of humus lability (Cmhs/Ch) and the quality of mobile humus substances (Cmha/Cmfa), and that contributed to the formation of the winter wheat yield.

Fig. 1. The amount of information transmitted from the indicators of soil organic matter to winter wheat yield. Designations: *Ch* is the carbon of humus, *Cmhs* is the carbon of mobile humic substances, *Cmha* is the carbon of mobile humic acids, *Cmfa* is the carbon of mobile fulvic acids, *Cmb* is the carbon of microbial biomass.

In 2019, characterized in the second quarter during the active spring-summer vegetation of winter wheat by insufficient moisture content of the territory ($\text{HTC}=0.85$) and increased heat, the greatest amount of information on the yield of winter wheat came from the content of mobile fulvic acids in the soil, the indicator of humus lability (Cmhs/Ch), the quality of mobile humus substances (Cmha/Cmfa), microbial biomass (*Cmb*) and the biogenicity of mobile humus substances (Cmb/Cmhs). Probably, these are the indicators that contributed to the

formation of the winter wheat yield even in this less favorable by weather conditions year.

Let us now consider the coefficient of information transfer efficiency, which shows the significance of a parameter for this phenomenon (winter wheat yield) and characterizes the degree of influence of each parameter (indicators of soil organic matter) on the phenomenon under study (Fig. 2,3) and the dependence of the phenomenon on the parameters.

Fig. 2. Coefficient of efficiency of information transfer from the indicators of soil organic matter to winter wheat yield in 2018. The symbols are the same as in Fig. 1.

In 2018 the most significant with a high degree of influence on the yield of winter wheat were $Cmhs > Cmfa > Cmhs/Ch > Ch > Cmha/Cmfa$, the coefficients of information transfer efficiency varied from 0.23 to 0.17. The average degree of correlation was observed between the yield of winter wheat and the biogenicity of mobile humus substances ($Ke=0.14$) and weak with Cng ($Ke=0.07$) and Smb ($Ke=0.06$). Moreover, the nature of the relationship between the yield of winter wheat and the indicators of soil organic matter is different. The relationship with the indicator of the quality of mobile humus substances in the soil ($Cmha/Cmfa$) is direct (disjunction), the yield increases with its increase. The relationship with mobile humus substances, mobile fulvic acids, and carbon of microbial biomass is reversed (conjunction), which indicates that the highest yield of winter wheat is formed at their low values in the soil. The relationship between the yield of winter wheat and humus, the indicator of its lability, with mobile humic acids is expressed by a logical function of the nonlinear product (with a tendency in the directions of the relationship to the average ranks of winter wheat yield).

In 2019 the most significant with a high degree of influence on the yield of winter wheat were $Cmb/Cmhs > Cmhs/Ch > Cmfa > Cmb > Cmha/Cmfa$, the coefficients of information transfer efficiency varied from 0.32 to 0.18. It was found that under more unfavorable hydrothermal conditions in 2019, the dependence of winter wheat yield on the biogenicity of mobile humus substances ($Cmb/Cmhs$), the lability of humus ($Cmhs/Ch$), microbial biomass increased and the influence of humus decreased. Especially sharply it increased due to the biogenicity of mobile humus substances. Perhaps, during the dry period, the role of the biological factor increases. The nature of the relationship changed, but not significantly: the relationship with the indicator of the quality of mobile humus substances ($Cmha/Cmfa$) remained direct, and with mobile fulvic

acids it changed to direct from reverse, i.e., the greater is the amount of them in the soil, the greater is the yield of winter wheat. The relationship with mobile humus substances, carbon of microbial biomass remained the same, and with the lability index of humus it became reversed.

Fig. 3. Coefficient of efficiency of information transfer from the indicators of soil organic matter to the winter wheat yield in 2019. The symbols are the same as in Fig. 1.

When determining the specific parameters of the indicators of the soil organic matter of typical chernozem, which are most closely related to the yield of winter wheat, it is possible to identify their optimal parameters using information and logical analysis. Those parameters of the indicators of the soil organic matter of typical chernozem are optimal, which correspond to the highest yield (highest rank) of the crop. In 2018 the highest yield rank of winter wheat was 5.46-7.24 t/ha, and in 2019 it was 5.39-7.19 t/ha.

Since the yield of winter wheat is most dependent on those indicators of soil organic matter that have a strong relationship with it, the optimal parameters of mobile humus substances, mobile fulvic acids, humus lability, humus, and the quality of mobile humus substances are presented in 2018 (Table 1).

It is found that when the content of carbon of mobile humus substances in the typical chernozem is 4,550-5,045 mg/kg, carbon of mobile fulvic acids is 1,880-2,200 mg/kg of soil, humus is 5.21-5.35, its lability is 14-16 %; the ratio of $Cmha/Cmfa$ (the quality of mobile humus substances) is 1.2...1.4, and with favorable moisture in the spring-summer period, the yield of winter wheat Synthetics will reach 5.46-7.24 t/ha.

Table 1. Optimal parameters of the indicators of soil organic matter of typical chernozem for winter wheat (yield 5.45-7.24 t/ha) in the topsoil in 2018.

Indicators of Soil Organic Matter	Optimal Parameters
Carbon of mobile humus substances ($Cmhs$), mg/kg	4,550-5,045
Carbon of mobile fulvic acids ($Cmfa$), mg / kg	1,880-2,200

Humus lability (Cmhs /Ch), %	14-16
Humus (H), %	5.21-5.35
Quality of mobile humus substances (Cmha/ Cmfa)	1.2-1.4

Under the arid conditions of the spring-summer period of 2019, the yield of winter wheat became more dependent on the biogenicity of mobile humus substances (Cmb/Cmhs), the lability of humus (Cmhs/Ch), the content of mobile fulvic acids, microbial biomass, and the quality of mobile humus substances, that is why the optimal parameters are presented for these indicators (Table 2).

It is established that under arid conditions it is possible to obtain the yield of winter wheat Synthetic 4.78-7.19 t/ha with the biogenicity of mobile humus substances (Cmb/Cmhs) in the arable layer of typical chernozem 12-15%, the lability of humus 14-16 %; the content of carbon of mobile fulvic acids 2,710-2,870 mg/kg of soil, carbon of microbial biomass 530-700 mg/kg, the ratio of Cmha/Cmfa (the quality of mobile humus substances) 1.2 to 1.4 with a humus content in the range of 5.24-5.38%.

Table 2. Optimal parameters of the indicators of soil organic matter of typical chernozem for winter wheat (yield 4.78-7.19 t/ha) in the arable soil layer in 2019.

Indicators of Soil Organic Matter	Optimal Parameters
Biogenicity of mobile humus substances (Cmb/ Cmhs), %	12-15
Humus lability (Cmhs /Ch), %	15-16
Carbon of mobile fulvic acids (Cmfa), mg/kg	2,710-2,870
Carbon of microbial biomass (Cmb), mg/kg	530-700
Quality of mobile humus substances (Cmha/C Cmfa)	0.75-0.95

4 Conclusion

Within the framework of the analyzed soil-plant system, on the basis of information and logical analysis, a strong and average relationship was established between the yield of winter wheat of the Synthetic variety and the content in the arable layer of typical chernozem, of humus, mobile humus substances, their quality and biogenicity, mobile humic acids, mobile fulvic acids, microbial biomass, and humus lability. This indicates that the yield of winter wheat Synthetic depends on these indicators of soil organic matter. Improving the quality of mobile humus substances ensures an increase in the yield level of winter wheat. The yield of the studied crop is more influenced by the lability of humus than the content of humus in the soil. It was revealed that in the more unfavorable by hydrothermal conditions 2019 (arid spring-summer period), the dependence of winter wheat yield on the biogenicity of mobile humus substances and the content of microbial biomass in the soil increased

especially sharply, and the influence of humus decreased. Depending on the year, the values of the information transfer coefficient and the degree of influence of each parameter on the yield of winter wheat changed, but the significance of the parameter remained in the studied years, the nature of the direction of relationship may change, but for individual indicators. The optimal parameters of soil organic matter in the arable layer of typical chernozem for obtaining the yield of winter wheat Synthetic 5.45-7.24 t/ha in a favorable by hydrothermal conditions and 4.78-7.19 t/ha in a dry year were established.

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