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METHODS OF SOIL-PLANT DIAGNOSTICS FOR WINTER WHEAT QUALITY FORECASTING

Olga A. Biryukova[1], Ivan I. Elnikov[2], Dmitry V. Bozhkov[1],

Anna M. Medvedeva[1], Vladimir V. Tereshchenko[1]

[1] Department of soil science and land evaluation, Department of biological sciences,

Southern Federal University, Rostov-on-Don, Russia

[2]Soil Science Institute named after V.V. Dokuchaev, Moscow, Russia

Abstract

The paper reveals findings of a long-term research into the reaction of winter wheat to the infield micro-variability of growth conditions using an integrated multi-element diagnostic system. A possibility is found to forecast the concentrations of crude gluten, macro- and micronutrients in the wheat grain based on the chemical composition of plants during a phase of stem elongation. It is determined that the concentration of gluten in the wheat grain depends on the supply of nitrogen to the plants and its balance with Zn, Mn, K and P.

Key words: *diagnostics, chemical composition of plants, winter wheat, black soil.*

1. INTRODUCTION

The existing publications (Boldyrev, 1964) show that chemical composition of grains is to a great extent determined by chemical composition of leaves, variable depending on the impact of climate, soil and other factors on the quality of future harvest. Therefore diagnostics of the yield capacity and the grain quality based on defining relations between the soil properties and the chemical composition of plants and seeds shall be considered as physiologically relevant. But such relations still remain underexplored. The urgency of their exploration is conditioned by a need to determine the optimal soil properties based on a wide range of criteria including the indicators of quality for plants nutrition. Creation of multi-factorial reference databases is essential for the improvement of the agro-ecological analysis of soil fertility and for the scientific support of the controlled yields with environmentally sound chemical composition, and also for the environmental monitoring. To date the linkage between the nitrogen supply to the plants and its content in the grains is the most studied. This issue is covered by many papers (Gritsenko, 1974; Mineev, Pavlov, 1981; Ames et al., 2003; Mineev, 2005; Mohammed et al., 2013). But the grain quality also depends on the content of other macro- and micronutrients, the interrelation of which with the chemical composition of plants in different phases of their growth and the soil properties is poorly studied.

The goal of research was to quantify relations between the content of crude gluten, different macro- and micronutrients in grains and the chemical composition of the above-ground biomass of winter wheat in the phase of stem elongation, and also the agrochemical properties of calcareous black soil.

2. MATERIALS AND METHODS

The object of study was the production plantings of winter wheat in the Rostov region. Data for experimental database was collected from diagonal small areas of 2*2 sq.m., annually segmented within a production planting during the stem elongation phase. In the phases of stem elongation and complete ripeness the plant productivity was analyzed and the plant and soil samples were taken. The soil samples were analyzed with standard methods (Workshop on Agricultural Chemistry, 2001).

With the help of X-ray fluorescence method (energy dispersive X-ray fluorescence method of plant analysis, 1983) the following macro-and micronutrients were identified in the plants: P, K, Cl, S, Si, Fe, Ni, Sr, Mn, Zn, Cu, Br, Cr, Al, Ca, Mg. The content of nitrogen in the plant and of gluten in the grain and the grain hardness were determined based on applicable GOSTs (GOST 10846-91, GOST 10987-76, GOST 13586.1-68). A created database was used to study the reaction of plants to the infield micro-variability of growth conditions with statistical methods. For a better analysis of this reaction and to study the balanceness of dynamics of various indicators the formulas of integrated operational diagnostics (IOD) were used. They were employed to record the

diagnostic data of plants nutrition with many different macro- and micronutrients (Elnikov, 2002). These formulas can also be used to analyze the linkage between the balanceness of dynamics of various indicators of plant and soil state through the change of an indicator taken as a function. IOD formulas also help to arrange the studied chemical elements by the degree of their deficiency or redundancy, and to distinguish the antagonistic elements and dominant elements, having the largest impact on the variability of an indicator taken as a function.

3. FINDINGS AND DISCUSSION

Within a production planting a large variation was observed in the infield yield (1.4 - 5.7 t/ha) and in a number of the most important indicators of grain quality: content of crude protein (12-16%), gluten (22-35%), hardness (45-72%); and the content of macro- and micronutrients in the grain. This suggests a high sensitivity of winter wheat to the infield micro-variability of soil conditions when wheat is grown in calcareous black soil. In order to examine the extent to which the plant reaction to the micro-variability of growth conditions is balanced with a spatial variation of agrochemical soil properties and the chemical composition of plants during the stem elongation phase the IOD formulas were analyzed. The study found that dynamics of agrochemical properties of soil and indexes of plants supply with macro- and micronutrients in the phase of stem elongation in transition from the micro-areas with high gluten content (35%) to the micro-areas with low gluten content (22%) can be expressed by the following IOD formula:

Gl,% - 35																							
								↓															
								22															
N	M	Hd	Pr	P_s	Cl	S	Hum		Si	Sr	Ni	Fe		Br	K_s	Cu	P		Ca_s+Mg_s		K	Mn	Zn
↓	↓	↓	↓	↓	↓	↓	↓		1	1	1	1		↑	↑	↑	↑		↑		↑	↑	↑
0.5	0.6	0.7	0.8	0.9	0.9	0.9	0.9							1.1	1.1	1.1	1.1		1.2		1.4	1.4	1.6

Legend (hereinafter): M - mass of 1 plant in stem elongation phase, Hd - grain hardness, Pr - protein; P_s - phosphorous labile, K_s - exchange potassium, Hum - humus, Ca_s, Mg_s – exchange calcium and magnesium in the arable soil layer. N, P, K, Cl, S, Si, Fe, Br, Ni, Sr, Mn, Zn - macro- and micronutrients in the above-ground biomass in the stem elongation phase. The numbers under the indicators refer to the corresponding supply indexes.

Special attention shall be given to the rules of IOD formulas reading. If index under the indicator is less than one, it means that the relative level of its supply and in case of linear dependence its absolute value are lower than the adopted reference value (or its maximum value in the analyzed data extract). Accordingly if index under the indicator is more than one, in absolute and relative terms its supply is redundant. If the ratio of indicators' values matches the reference value, their supply indexes in the studied conditions are equal to 1. And conversely the stronger is the cultivar reaction by selected criterion to the changes in relative and absolute levels of diagnostic indicators, the larger number of indicators will have values differing from 1. This is the basis for conclusions regarding the plants sensitivity to changes in monitored indicators and the degree of their deficiency compared to reference values.

The presented IOD formula shows that the winter wheat in the calcareous black soil strongly reacts to the infield variability of growth conditions by changes in crude gluten content in the grains. This reaction is balanced with the change in the correlation of a large number of indicators. The formula shows that the reduction of gluten content in the grain leads to the lower weight of one plant, reduced content of protein and lower hardness of grain, and by the levels of supply the nutrients can be divided into two groups opposite by the direction of change: S, Cl, N - supply indexes are reduced; Cu, P, K, Mn, Zn - supply indexes are increased. The correlation between agrochemical properties of soils is also changeable. The winter wheat strongly reacts to the change in the balance of soil properties, especially to the relation between the content of exchange potassium in arable soil layer and humus and the total absorbed bases. This relation according to the large number of experimental data (Fig. 1) is curvilinear.

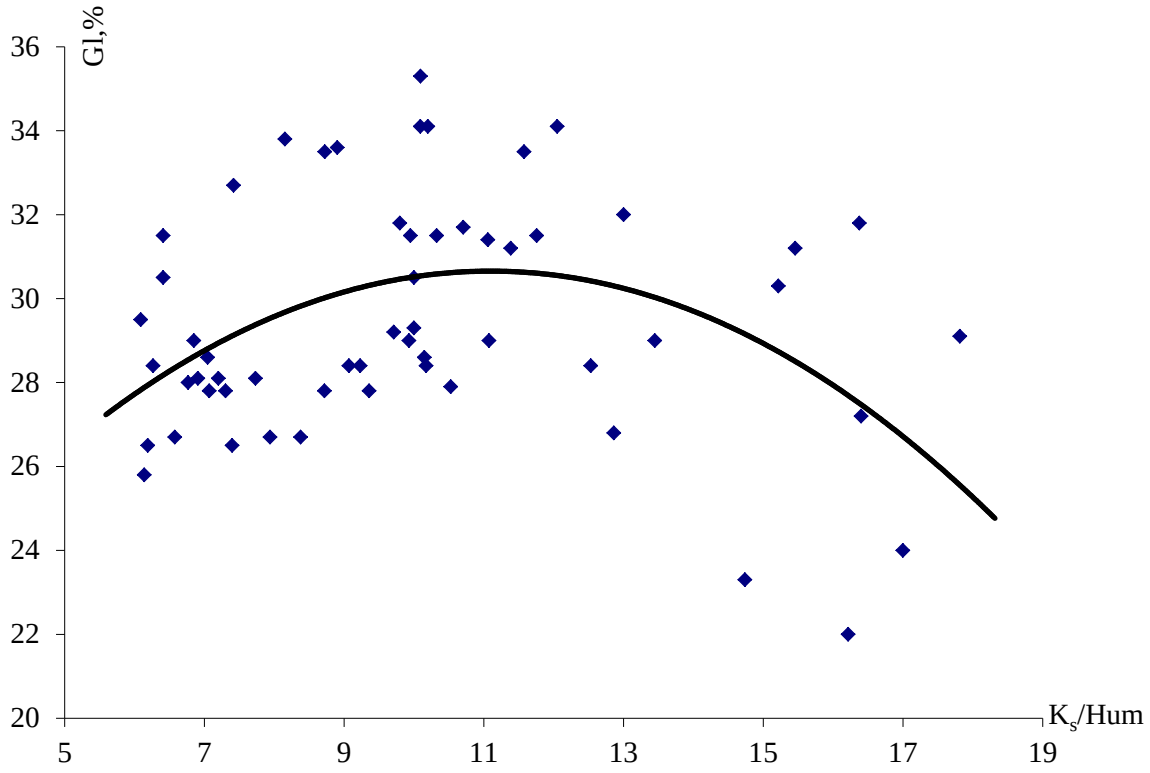


Fig. 1. Changes in gluten content in wheat grain (Gl,%) depending on the correlation between exchange potassium and humus (K_s/Hum) in the arable soil layer.

IOD formula also indicates that the increase in the nitrogen supply in calcareous black soil is accompanied by a deeper deficit in manganese, zinc and potassium. This can be explained by the fact that the increased nitrogen supply leads to the increased need of plant in these elements, but their lability in the calcareous soils is as a rule low because of their alkaline reaction. Thus the unbalanced increase in the nitrogen supply to the wheat grains in the examined black soil can be accompanied by reduced Mn and Zn supply. This adversely affects the quality of plants, as Mn and Zn are the nutrients, the lack of which prevents the use of amino acids for the proteins synthesis (Zhiznevskaya, 1972). Apart from that the Mn deficit leads to the impaired photosynthesis, which may cause reduction in leaf carbohydrate levels, and it is referred to the key factor limiting the growth of root systems (Bityutsky, 1999). The obtained evidence shows that the infield variation in gluten content in the winter wheat grains in the calcareous black soil is not chaotic and to a large extent is determined by the spatial heterogeneity of the soil properties that impact the nitrogen supply to the plants and its balance with K, Mn, Zn, P. This is also confirmed by the linear regression models shown below. However despite the statistical validity of linear regressions, their determination coefficient is lowered due to the incomplete coverage by regression model of factors affecting the gluten accumulation in the grain.

$$\mathbf{Gl = 30.1 + 3.2N + 0.18M - 0.48P_s - 2.5P - 1.6Mg_s - 1.6K + 0.14Zn} \quad (1)$$

(F=1.8 with the degree of freedom 44 and 37) $R^2 = 0.52$

$$\mathbf{Gl = 54.7 + 0.09Mn - 6.9P - 7.1M/Mg_s - 7.9M/Ca_s + Mg_s - 3.3Mg_s/N - 41.2M/Mn + 2.4M} \quad (2)$$

(F=2.0 with the degree of freedom 58 and 51) $R^2 = 0.54$

Legend: Gl - gluten content in the grain, %; M - mass of 1 plant in stem elongation phase, g; P_s, Ca_s, Mg_s - labile phosphorous, exchange calcium and magnesium in the arable soil layer, mg/kg; N, P, K, Mn, Zn - content of macro- (%) and micronutrients (mg/kg) in the above-ground plants in the stem elongation phase.

For the enhanced accuracy of forecasting the gluten content in the grain the consideration of possible yield capacity of wheat within the monitored area is of high importance. The research results (Fig. 2) show that the

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dependence of gluten content in the wheat grain on its yield capacity is curvilinear. That's why it is important to make correct assumptions on the range of yield variations, within which a positive linear correlation of yield and gluten content in the grain is possible under the studied conditions. The width of this range depends on the moisture reserves in the soil and soil richness in the nitrogen. According to Fig. 2 this range is rather wide for the calcareous black soil (from 1.4 to 4.0 t/ha). With further increase in yield the content of crude gluten stabilizes and shows a downwards trend, which is explained by the reduced supply of nitrogen to the plants. It is partially confirmed by the works of Gritsenko (1974), Stepien & Wojtkowiak (2013), which show that the protein content in the grain is indirectly related to the weather conditions and depends directly on the nutrient, predominantly nitrogen status of soil, shaped under the influence of a range of meteorological and agrotechnical conditions. Thus in calcareous black soil the content of gluten can be forecasted based on the value of yield alone. However it would be hard to detect the factors of soil fertility which cause the changes in gluten content and the impact of soil properties and supply of plants with macro- and micronutrients on this indicator, but it is essential for the development of technologies controlling the productivity and the quality of crops.

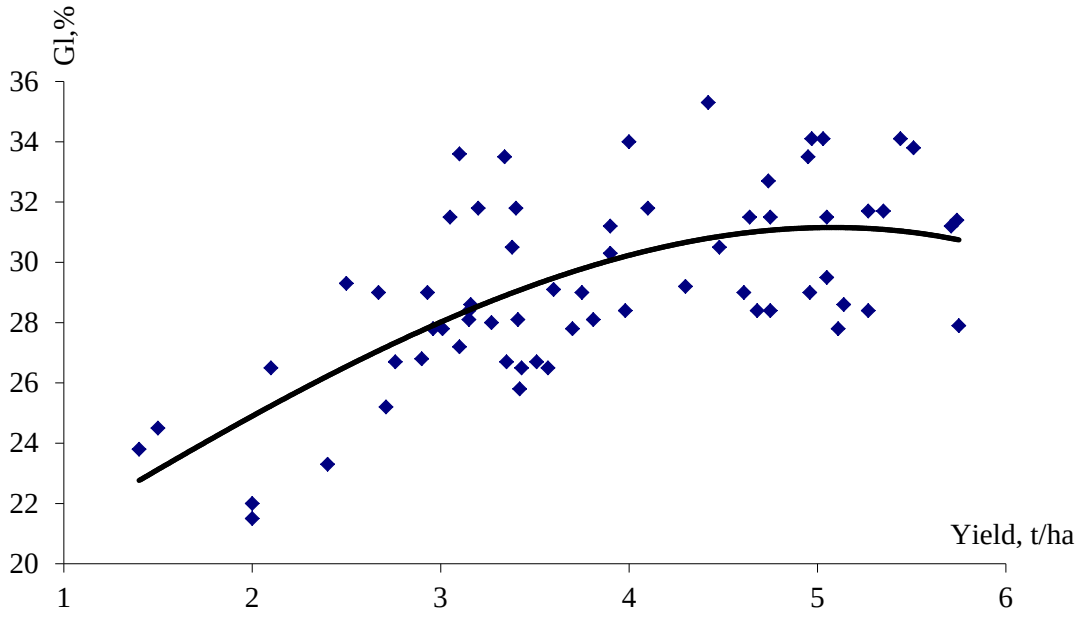
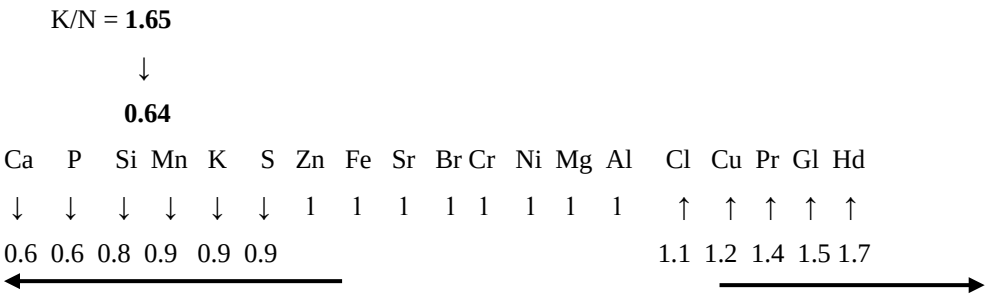


Fig. 2. Changes in gluten content in wheat grain (Gl,%) depending on its yield capacity (Yield, t/ha)

Let us highlight another important but poorly studied issue: the correlation of the most important grain quality indicators with the grain ultimate composition and chemical composition of the above-ground plants in different phases of their development. Examination into the peculiarities of this relation helps to identify the key indicators influencing the integral assessment of grain quality at the early stage of yield formation. These indicators may be used as criteria for the evaluation of soil properties and other factors conformance to the needs of plants for production of the grains with the controlled content of chemical elements. In addition it shall be taken into account that changes in the correlation between the grain quality indicators and the content of macro- and micronutrients may have a strong impact on the environmental safety of the grain. Studies revealed that change in these correlations in the wheat grain is intense and depends on the quality (balanceness) of grain nutrition in the phase of stem elongation. The strongest and statistically valid influence on the integral evaluation of the wheat grain quality is exerted by the disturbed balance in the content of the following chemical elements in the above-ground biomass: K/N, Mn/N, N/P, Zn/N, Sr/Ca. The IOD formula below shows the course of changes in the supply indexes of different elements and their balance versus the content of gluten, protein and hardness with reduction in K/N ratio in the above-ground plants during the stem elongation phase from 1.65 to 0.64.

The balanceness of the K/N ratio changes in the above-ground wheat biomass and the chemical composition of the grain:



The results show that changes in the wheat nutrition with potassium and nitrogen influence the balanceness of content of a large number of macro- and microelements in the wheat grain. While the direction of change in the supply indexes and the most important indicators of grain quality at K/N ratio reduction in the above-ground biomass is different: Cl, Cu, Pr, Gl, Hd - supply indexes increase; Ca, P, Si, Mn, K, S - supply indexes decrease. At the increase of K/N ratio in the plant the change of the mentioned chemical elements has the opposite direction. Therefore the balanceness of the macro- and micronutrients content in the wheat grain with the important indicators of its quality is not permanent and may change depending on the conditions of plants nutrition already at the early stage of their development. For agroecological evaluation of the soil properties for different cultivars it is important to know, which disturbances of the plants nutrition at different stages of their development correlate with the content of chemical elements in the grain, and which of them in the monitored conditions are the most environmentally destructive. The content of chemical elements in the wheat grain the same as correlations between the content of protein and crude gluten and hardness depend on the quality of plants nutrition at the stage of stem elongation, which is confirmed by the results of correlation analysis.

Below there are the chemical elements in grain, the changes of which correlate with the content of chemical elements and their ratios in the above-ground wheat biomass.

Element content in the grain	Cu	Mn	Br	Zn	Ca	K	P	Pb	Sr
Correlation of elements in the above-ground biomass	Ni/Sr	Mn/Sr	N/Si	Si/Cl	N/K	Ca/Sr	N/K	Mn/Sr	
Elements content in the above-ground biomass	Sr	Si	N	N		Sr			Sr

Correlation coefficients are statistically valid with a probability of at least 95%, but in absolute terms they are not big (0.4 - 0.6). But the existence of reliable correlative relations between the content of elements in the grain and the chemical composition of the plants gives a possibility to use this knowledge for the agroecological evaluation of soil properties to get a yield of wheat with high ecological quality in terms of content and correlation of macro- and micronutrients. This issue requires further research. For the calcareous black soil it is especially important to control the correlation between calcium and other elements. Based on the disturbance in Ca/P, Ca/Sr ratios in the cut plants and feedstuff ecological stress levels of certain areas are assessed (Ermakov, Bashkin & Snakin, 1993), which confirms the importance of these criteria for ecological control of plant products quality and human-induced effects on soil. According to our data Sr content in the above-ground biomass in the stem elongation phase correlates with its content in the winter wheat grain. Increase in Sr content in the grain is accompanied with unbalanced change in the content of Ca and other elements, that can lead to ecologically dangerous disturbance in their correlations at different concentrations (increased or reduced) of gluten and protein. This points to the urgency of the development of plant-based diagnostic methods to forecast the strontium and calcium content in the wheat grain for the integral assessment of its quality and soil conditions of its growth.

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CONCLUSION

The use of an integrated system of plants nutrition diagnostics for a study of the infield reaction of plants to changing growth conditions is significantly expanding the possibilities of grain quality forecasting and the evaluation of soil properties conformance to the needs of the plants. It is shown that the forecasting and integral evaluation of wheat grain quality in the calcareous black soil shall be performed with account of balanceness of macro- and micronutrients content in the wheat grain and the above-ground biomass in the stem elongation phase, and also with account of soil features correlation. It is established that the gluten content in the winter wheat grain in the calcareous black soil to a large extent depends on the balanceness of N with Mn, Zn, K in the plants during the stem elongation phase and the correlation between potassium and humus in the soil.

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