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Standarding the action of microelements based on the methodology of the integration system of soil-plant operational diagnostics of plant nutrition ("ISPROD")

Standardizacija delovanja mikroelemenata na osnovu metodologije integracionog sistema zemljište-biljka operativne dijagnostike ishrane biljaka („ISPROD")

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Abstract: Based on the principles of Integration of the soil-plant system operational diagnostics of plant nutrition set standards for the content of microelements in soil and plants, taking into account the specific natural conditions and the magnitudes of yield formation. Based on conducted years of research developed the formula for calculating the optimal doses of micronutrients for optimal macro background. As a result of the research generated a mathematical model based on the content of microelements in soil from the applied doses of micronutrients in these soils. Contains the optimal ratio of microelements in soil, plants, characterizing a harmonious mineral nutrition culture. In the field of optimal dosages of micronutrients established factors of intensity of the action of trace elements contained in the plant ("b", mg/kg), on the formation of the magnitude of the yield of green mass of fodder crops during the making of Cd, Ni, Zn, Se.

Keywords: soil, plant mineral nutrition, trace elements.

Sažetak: Na osnovu principa Integracije sistema zemljište-biljka operativna dijagnostika ishrane biljaka postavlja standarde za sadržaj mikroelemenata u zemljištu i biljkama, uzimajući u obzir specifične prirodne uslove i veličine formiranja prinosa. Na osnovu sprovedenih višegodišnjih istraživanja razvijena je formula za izračunavanje optimalnih doza mikronutrijenata za optimalnu makro pozadinu. Kao rezultat istraživanja generisan je matematički model zasnovan na sadržaju mikroelemenata u zemljištu iz primenjenih doza mikroelemenata u ovim zemljištima. Sadrži optimalan odnos mikroelemenata u zemljištu i biljkama, karakterišući harmoničnu kulturu mineralne ishrane. U oblasti optimalnih doza mikroelemenata utvrđeni su faktori intenziteta delovanja elemenata u tragovima sadržanih u biljci („b", mg/kg), na formiranje veličine prinosa zelene mase krmnih useva pri izradi Cd, Ni, Zn, Se.

Ključne reči: zemljište, mineralna ishrana biljaka, elementi u tragovima.

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INTRODUCTION

Analyzing the currently available data on the standardization of the content of microelements in environmental objects, most researchers come to the conclusion that microbiologists, soil scientists, agrochemists, veterinarians, hygienists, and doctors should jointly develop MPCs (Ilyin, 1991).

Determining the mathematical patterns of the action of microelements in trophic chains, taking into account geochemical, agroecological conditions, and the specific influence of a certain chemical element on living organisms, is of particular importance in environmental regulation. The standards for the action of chemical elements in trophic chains obtained as a result of modeling make it possible to "manage" the process of mineral nutrition of plants and animals, as well as to diagnose and prevent negative processes caused by an excess, deficiency or imbalance of microelements in environmental objects (Ćupić et al., 2024).

1. METHODS

Taking into account the analyzed theoretical material on the issues of rationing of chemical elements, we developed a dynamic scheme for the interaction of microelements in the soil – fertilizers – plants – animals system based on the principles of ISPROD (Fig. 1) (Ermokhin, Sindireva, 2011).

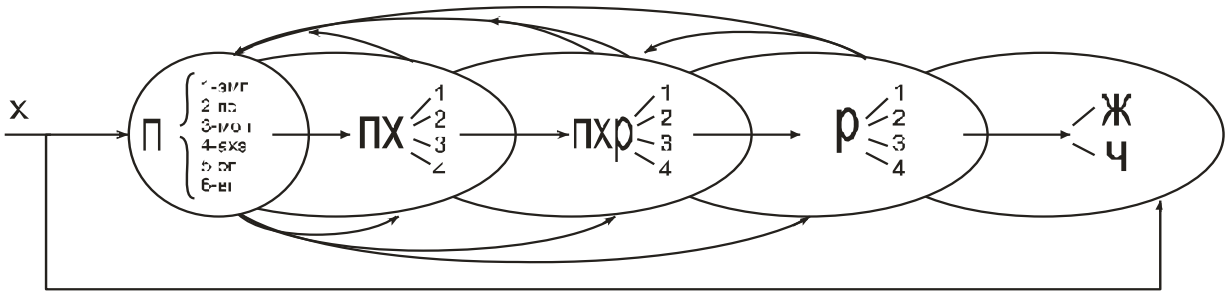

Figure 1 - Dynamic scheme of interaction of chemical elements in the system soil – fertilizers – plants – animals

Legend

	Chemical element
Р (П) The soil. Initial state	1 - mobile elements of mineral nutrition (EMP) 2 - gross content of chemical elements (CE) 3 - soil microorganisms (SOM) 4 - accumulation of chemical elements along horizons (AH) 5 - soil organic matter (SO) 6 - soil moisture (SM)
РН (ПХ) Interaction of elements with soil	1 - dissolution and transformation of chemical elements (X) 2 - "b" intensity of action of element "X" on the soil 3 - accumulation of chemical elements along horizons (AChE) 4 - change in microorganisms in quantitative and species ratio (MOP)
РНR (ПХР) Interaction of chemical elements with a plant	1 - chemical composition of plants (leaves) in ontogenesis (CR) 2 - biometric plant diagnostics (BD) 3 - plant (leaf) diagnostics (RD) 4 - interaction "X" in the "soil-fertilizer-plant" system (SFUR)
R (Р) Result	1 - optimal levels (ratios) of "X" in soil and plants 2 - planned harvest (increase) 3 - increasing soil fertility (SFP) 4 - harvest quality (QU)
F H (Ж Ч) Animal - Human	MDH - modeling of the action of a chemical element in the "PROD" system - soil-plant operational diagnostics on animal and human health

Yu. I. Ermokhin, students of his scientific and pedagogical school "Integrated system of soil-plant operational diagnostics of plant nutrition" ("ISPROD"), developed mathematical models for diagnosing mineral nutrition, the efficiency of using fertilizers, the size and quality of the crop based on the following principles (Ermokhin, 1983):

1) the ability of soils to satisfy the need of plants for nutrients (nitrate nitrogen, mobile phosphorus, exchangeable potassium, mobile microelements,

quantitative characteristics of soil enrichment with biological nitrogen);

2) the needs of plants for nutrients and their ability to assimilate these substances in specific conditions of agricultural production (CIS, CIU, PES, removal of nutrients);

3) nutritional state of plants and calculation of doses of fertilizers during the period of growth and development (optimal levels and harmonious (balanced ratio of macro- and microelements in plants according to phases of growth and development, Kp - coefficient of nutrient requirement, "b" - coefficients of intensity of action of the introduced (or incoming) element on the chemical composition of plants).

2. RESULTS

When assessing the effect of microelements in ecosystems, one of the most important parameters is the productivity and yield of cultivated plants. The main way to assess the need of plants for fertilizer is field experience, which makes it possible to establish the role of individual nutrients in increasing crop yields, to establish patterns between the content of nutrients in the soil, plants, and the size and quality of the crop (Afendulov, Lantukhova, 1973).

In order to create optimal conditions for the formation of the yield of cultivated crops, the method of soil diagnostics is widely used, both here and in foreign countries (Ermokhin, 1983). Using soil chemical analysis data, it is possible to predict the effectiveness of the use of mineral fertilizers.

In connection with the above, there is a need to solve the problem of regulating the content of chemical elements in soil and plants, taking into account specific natural conditions and yield formation values (Ermokhin et al., 2002; Sindireva, 2012). This will allow you to control the process of mineral nutrition of plants and the formation of the size and quality of the crop.

Therefore, our task was to bring the content of the studied elements in the soil to the optimal level for balanced nutrition of crops. To calculate the required doses of fertilizers, formula (1) was used:

$$Д = \frac{Э_0 - Э_ф}{"b"}, \quad (1)$$

where $Э_0$, $Э_ф$ – optimal and actual content of the element in the soil, mg/kg;

"b" – intensity coefficients of action of 1 kg of cadmium (0.011), nickel (0.005), zinc (0.011), selenium (0.0012), mg/kg in a soil layer of 0-30 cm.

It has been established that the relationship between the dose of fertilizers and nutrients in the soil is inversely proportional; therefore, the higher the content of the studied microelements in the soil, the lower the dose of fertilizer (Ermokhin, 1983). Mathematically, this can be expressed by the following formula:

$$Д_o \cdot X_o = Д_n \cdot X_n \quad (2)$$

where $Д_0$ is the established optimal dose of fertilizer nutrients in kg a.i./ha with the corresponding content of elements in the soil before sowing, mg/kg (X_0);

$Д_n$ – dose of fertilizers in kg a.i./ha, predicted depending on the content of nutrients in the soil of a particular field, mg/kg (X_n).

From here:

$$Д_n = \frac{Д_o \cdot X_o}{X_n}. \quad (3)$$

This calculation method allows us to specify the dose of fertilizers depending on the chemical composition of the soil, increase their effectiveness for various plants and obtain high yields of good quality. This method should also be used for microelements that have a narrow line between toxicity and necessity, in particular for Cd, Ni, Zn, Se. The presented approach may also be used to determine environmentally safe levels of anthropogenic input of these chemical elements into the soil, as well as to predict the accumulation and impact of these elements on the yield and quality of crops. Taking into account many years of research, formulas have been developed for calculating optimal doses of microfertilizers on an optimal macronutrient background using spring rape as an example (Table 1).

Table 1. Calculated doses of microelements obtained on the basis of many years of field experiments with fertilizers and chemical analysis of soil

Element	Optimal dose of microelements in the experiment (*Before*), kg/ha	Initial microelement content in soil (X_0), mg/kg	Calculated dose of microfertilizers ($Д_n$), kg/ha
Ni	3,6	0,51	$Д_n = \frac{1{,}84}{Ni_{мг/кг}}$
Zn	26,2	0,66	$Д_n = \frac{17{,}3}{Zn_{мг/кг}}$
Se	11,7	0,052	$Д_n = \frac{0{,}61}{Se_{мг/кг}}$

The proposed formulas for determining the approximate doses of microfertilizers for the crops under study allow us to move away from simple empiricism with the use of fertilizers and focus on specific doses taking into account the content of the available element in the soil.

As a result of the research, mathematical models of the dependence of the content of microelements in the soil on the doses of incoming microfertilizers were obtained. The established coefficients "b" made it possible to calculate the amount of microelements (kg/ha) required to increase the content of mobile forms of Cd, Ni, Zn in the soil by 1 mg/kg:

Cadmium $\frac{1мг/кг}{0{,}011мг/кг} = 90$ kg/ha;

Nickel $\frac{1мг/кг}{0{,}005мг/кг} = 200$ kg/ha;

Zinc $\frac{1мг/кг}{0{,}011мг/кг} = 90$ kg/ha;

Selenium $\frac{1мг/кг}{0{,}0012мг/кг} = 835$ kg/ha.

Using data on the optimal ($Э_0$) and actual ($Э_ф$) levels of microelements in the soil for a given crop, the dose of Cd, Ni, Zn, Se (kg/ha) per plant can be calculated using formulas (4-7):

$$ДCd = (Э_o - Э_ф) \cdot 90 \quad (4)$$

$$ДNi = (Э_o - Э_ф) \cdot 200 \quad (5)$$

$$ДZn = (Э_o - Э_ф) \cdot 90 \quad (6)$$

$$ДSe = (Э_o - Э_ф) \cdot 835 \quad (7)$$

Taking into account the best doses of microelements (for example, Ni, Zn, Se) with an optimal macronutrient background, taking into account the experimental data obtained, we can conclude about the optimal content of microelements in the soil for crop nutrition (C_0, mg/kg), for example, for spring rape, according to formulas (8-10):

Nickel:

$C_0 = C_1 + Д \cdot$"b" = 0,51 + 3,6·0,005 = 0,53 (8)

Zinc:

$C_0 = C_1 + Д \cdot$"b" = 0,66 + 26,2·0,011 = 0,95 (9)

Selenium:

$C_0 = C_1 + Д \cdot$"b" = 0,52 + 11,7·0,0012 = 0,066 (10)

To form a high yield in quantitative and qualitative terms, it is necessary to know, in addition to the optimal levels of microelements in the soil, their balanced combination when feeding the crop plant.

Table 2 shows the optimal ratio of microelements in the soil, which characterizes the harmonious mineral nutrition of spring rapeseed, which allows determining the element action coefficient (Kd) using the formula:

$$Кд \frac{Zn : Ni : Cd : Se : Cu : Pb(оптим)}{Zn : Ni : Cd : Se : Cu : Pb(фактич)} \quad (11)$$

Table 2. Optimal ratio of elements in meadow-chernozem soil

Before sowing rapeseed	Microelements	Zn ≈ 6,3 · Cd ≈ 1,8 · Ni ≈ 14,4 Se
	Macroelements	P_2O_5 ≈ 10 · N - NO_3 ≈ K_2O

Thus, the obtained mathematical models make it possible to predict and adjust the optimal content and ratio of microelements in the soil as a result of their anthropogenic input; doses of microfertilizers, taking into account the content of chemical elements in the soil and the need for these nutrients to form the predicted yield and quality of crop products.

Optimal levels of nutrients in plants depend on the crop, the phase of its development, the level of yield and methods for determining chemical elements (Ermokhin, 1983; Ermokhin, Sindireva, 2011; Sindireva, 2011; Tserling, 1990).

In the area of optimal dosages of microfertilizers, the intensity coefficients of the action of microelements contained in the plant ("b", mg/kg) on the formation of the yield of green mass of forage crops (t/ha) have been established with the main application of Cd , Ni , Zn , Se (Table 3) (Ermokhin et al., 2002; Ermokhin, Sindireva, 2011; Sindireva, 2011; Tserling, 1990).

Based on many years of data from field experiments with microfertilizers, the obtained yield values and the chemical composition of plants, and the identified mathematical dependencies, we established the optimal levels of macro- and microelements in plants corresponding to maximum yield (Table 4).

Table 3. Action intensity factors ("b") units Cd, Ni, Zn, Se contained in plants (in mg/kg) on the formation crop yield (in t/ha)

Culture	Action intensity coefficients (“*b*”)			
	Cd	Ni	Zn	Se
Roots				
Beet	78	36	1,8	**
Carrot	n*	18,2	4,64	-
green mass				
Rape	8,15	6,42	0,34	1,1
Astragalus	-	-	-	0,75

Note: *n – no increase in yield, ** – no data

Table 4. Optimal content of chemical elements in spring rape and Astragalus galegidae plants

Plant	Optimal content								
	macroelements, %			microelements, mg/kg					
	N	P	K	Se	Cd	Ni	Zn	Cu	Pb
Above ground mass									
Rape	3,7	0,6	3,3	1,2	0,9	5,1	44,0	3,6	3,5
Astragalus	3,6	0,7	2,0	1,9	0,04	1,4	7,0	2,6	1,0
Beet	1,8	0,5	2,5	*	0,6	3,2	26,9	6,9	3,8
Carrot	1,9	0,4	2,6	-	0,4	2,0	17,3	4,4	3,6
Root vegetable									
Beet	1,4	0,5	1,9	-	0,3	1,1	17,3	5,6	2,6
Carrot	1,0	0,6	2,4	-	0,2	1,0	22,5	3,7	1,3

Note –* no data available

Our research has shown that with the additional intake of a chemical element into the environment, the entire chemical composition of the plant organism changes due to the manifestation of antagonism-synergism between ions both in the environment surrounding the plant (soil) and inside the plant organism (Ermokhin, Sindireva, 2011). As a consequence, it seems necessary to establish the relationship between macroelements and microelements in the plant organism on the most favorable macro- and microelement backgrounds with the elements being studied. The resulting ratios make it possible to normalize the chemical composition of plants in order to create crop products that are optimal in terms of productivity and quality. Table 5 shows the optimal ratios of macro- and microelements in vegetable and forage plants.

Table 5. Optimal ratio of chemical elements

Culture	Optimal ratio	
	macronutrients	microelements
Beet		
Above ground mass	N ≈ 3,4 · P ≈ 0,7 · K	Zn≈45 · Cd≈8,3 · Ni≈3,9 · Cu≈7 · Pb
Root vegetable	N ≈ 2,9 · P ≈ 0,7 · K	Zn≈56 · Cd≈8,3 · Ni≈3,4 · Cu≈7 · Pb
Carrot		
Above ground mass	N ≈ 4,2 · P ≈ 0,7 · K	Zn≈42 · Cd≈8,1 · Ni≈4,4 · Cu≈5 · Pb
Root vegetable	N ≈ 1,9 . P ≈ 0,4 · K	Zn≈52 · Cd≈8,3 · Ni≈2,7 · Cu≈6 · Pb
Spring rape		
Above ground mass	N ≈ 6,2 · P ≈ 1,1 · K	Zn≈48 · Cd≈8,6 · Ni≈12 · Cu≈12,6 · Pb≈36,7 · Se
Astragalus galegidae		
Above ground mass	N ≈ 5,1 · P ≈ 1,8 · K	Zn ≈3,7 · Se ≈ 175 · Cd ≈5,4 · Ni ≈2,7 · Cu ≈7 · Pb

The established optimal levels of supply of nutrients to crops make it possible to correctly interpret the actual results of chemical analysis of plants in a natural environment. K.P. Magnitsky (1964) noted that when diagnosing plant nutrition, it is important to determine in the soil and plants (leaves) not only

the element for which the need must be established, but also others that influence the level of plant nutrition with this element (Magnitsky, 1972).

Vegetable and forage plants suffer from a deficiency or excess of macro- and microelements in plants of two types: absolute and relative. If there is an absolute deficiency of any microelement in the plant, it is enough to bring its content to the optimal level, taking into account the requirement coefficient (K_n) according to formula (11):

$$Kn = \frac{оптимальныйуровеньэлементаврастении, мг/кг}{фактическийуровеньэлементаврастении, мг/кг} \quad (12)$$

If there is a relative lack of nutrients in the soil, that is, an imbalance in the ratio, it is necessary to determine the missing element for a balanced balance and restore the balance by applying fertilizers. In this case, K_n for microelements is determined by formula:

$$Kn = \frac{Zn : Ni : Cd : Se : Cu : Pb(оптим)}{Zn : Ni : Cd : Se : Cu : Pb(фактич)} \quad (13)$$

where the numerator is the optimal ratio, and the denominator is the actual ratio of microelements in plants.

The requirement coefficient (K_n) shows how much the content of the missing element or elements in the plant should be increased or decreased for harmonious nutrition and, accordingly, normal growth and development of plants.

Thus, strict regulation of the content and ratio of basic macroelements (N, P, K) and microelements (Cd, Ni, Zn, Se, Cu, Pb) in plants will make it possible to predict the effectiveness of microfertilizers, the amount of crop yield, as well as the environmental situation associated with chemical load in the soil-plant system..

CONCLUSION

The methodology for regulating the action of microelements in the soil-plant system, which was based on the principles of the ISPROD system, was developed taking into account the provisions on the presence of a close relationship between external nutritional conditions and internal metabolic processes in plants, on the close dependence of the size, quality of the harvest and the supply of elements nutrition in plants depends not only on the absolute content, but also on the ratio of these elements to each other.

The identified patterns make it possible to optimize the supply of microelements to plants using the developed regulatory parameters of the ISPROD system, and thereby manage the process of formation of the size and quality of the yield of cultivated crops, as well as establish gradations and ratios of chemical elements in the soil and plants, taking into account agronomic and sanitary-hygienic aspects.

The obtained research results must be taken into account when cultivating crops. At the same time, it is necessary to take into account the sanitary and hygienic aspect of rationing when further consuming plants for human and animal food. Identifying the characteristics of the behavior of microelements in the soil – plant – animal system is necessary for the prevention and treatment of diseases caused by excess, deficiency or imbalance of microelements.

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