The mathematical modeling of mobile zinc and cobalt level in soil

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Abstract. According to the research results, the coefficients of applied zinc and cobalt fertilizers activity are calculated. It is established that each kilogram of zinc and cobalt applied into the soil layer of 0-30 cm increases the level of mobile zinc by 0.012 and 0.013 mg/kg of soil, mobile form of cobalt by 0.028 and 0.025 mg/kg of soil.

1. Introduction

Micronutrients play a significant role in the fertilizing of flax. Flax reacts to their deficiency by underdevelopment and stagnation [1, 2]. Speckled, marginal or complete chlorosis, death of growth points, formation of a thick rosette, death of the buds and yellowing and dying of the top of the plant are the signs of micronutrient deficiencies. The weather conditions of the vegetative period of flax also influence the availability of micronutrients to plants; under arid conditions, their deficiency and the symptoms caused by them sharply increase. The positive effect of microelements on the flax harvest is caused not only by the fact that they are essential nutrients, but also by their effect on the soil microflora, on the relationship between plants and soil microorganisms [3-6].

A significant impact on the formation of the crop and its quality indicators has the availability of soil microelements. Trace elements enhance plant productivity, improve product quality, and increase resistance to adverse factors (drought, disease). At their optimum content in the soil, plants better absorb nitrogen, phosphorus, potassium from the soil and fertilizers. Plants need micronutrients in very small amounts [7-11].

2. Objects and research methods

The objects of research were flax in variety Sokol and the soil of the experimental plot. The Sokol variety was created in the Siberian Experimental Station VNIIMK (Federal Scientific Center “V.S.Pustovoit All-Russian Research Institute of Oil crops”) by the method of individual selection from a hybrid population from crossing varieties (Soyuz x Start) x Rassvet.

The soils of the experimental area are ordinary thin, low-humus chernozem soils, formed at groundwater levels of more than 6 m.

Ordinary chernozem soils are the most common zonal soils of the steppe and southern parts of the forest-steppe zone of the Omsk Region.

Research was conducted on the experimental field of the Agrotechnical College of the Poltava region located in the steppe zone of Western Siberia. This zone is extreme continental, and its continentality
increases as it moves from north to south. The general features of the temperature regime of the territory are characterized by a harsh long winter, relatively short but hot summer, short transitional seasons in spring and autumn, late spring and early autumn frosts. The temperature regime is characterized by rapid changes by year, month, and even during the day. The absolute annual amplitude of air temperature is quite significant (80–90°C), which emphasizes the continental climate. According to the degree of moisture supply, the steppe zone of Western Siberia belongs to areas of unstable humidification: the average annual precipitation is 280–300 mm, most of which, 70–80% of the annual amount, and falls in the summer period.

The experiment was carried out with flax cultivation and on the fallow plot area. Zinc and cobalt fertilizers were applied to the soil in the spring before sowing flax; on the fallow land at the same time. The dose of fertilizer was calculated, depending on the level of the applied element in the soil and their MAC.

3. Research results
In matter of mobile Zn and Co in soil, a higher level of zinc and cobalt was identified in soil of the fallow field compared to the area where flax was cultivated. By the method of mathematical analysis, it was found that with a high level of correlation between “doses of Zn → level of Zn in soil” as at the fallow land and in flax cultivation (r1 = 0.99; r2 = 1), the intensity factors of the unit of X1, X2 Zn (1 kg/ha) for the content of mobile Zn (U1) in soil of the fallow field amounted to 0.012 mg/kg and in the soil under flax 0.01030 mg/kg U2 (Equation 1 and 2, figure 1):

\[ U1 = 0.012 \times X1 + 0.63 \quad r = 0.99; \]
\[ U2 = 0.013X2 + 0.54 \quad r = 1.00; \]

Equations 1 and 2 identify that each kg of applied zinc to soil (X1, X2) increases the content of mobile Zn in soil (“bZn”) by 0.012 (Y1) and 0.01030 (U2) mg/kg of soil. Studies show that 1 mg of Zn/kg of soil corresponds on the fallow field to an equivalent amount of 81 kg of zinc fertilizers (1/0.012 mg / kg) and 77 kg (1 / 0.01030 mg / kg) in the soil under oil flax.

There is a direct and inverse (response) relationship in the system: ”fertilizer - soil” which is characterized by a high identification of the soil response to changes in the content of Zn and Co in soil. It is presented in table 1, described by figure 1 and equation (3 and 4):

\[ \text{Zn, mg/kg} = 0.0125 \times \text{Zn, kg} + 0.585; \]
\[ \text{Co, mg/kg} = 0.0265 \times \text{Co, kg} + 0.21; \]

| Table 1. Soil response when applying nutrients with fertilizers to the soil layer of 0–30 cm. Field experiments 2015–2017. |
|---------------------------------------------------------------|
| Variants | Co, mg/kg | Zn, mg/kg |
| Fallow land | |
| Control w/o Zn and Co | 0.24 | 0.63 |
| Zn 0.25 MAC | - | 0.87 |
| Zn 0.50 MAC | - | 1.11 |
| Zn 0.75 MAC | - | 1.36 |
| Zn 1,00 MAC | - | 1.60 |
| Co 0.25 MAC | 0.36 | - |
| Co 0.50 MAC | 0.48 | - |
| Co 0.75 MAC | 0.59 | - |
| Co 1,00 MAC | 0.72 | - |
| Flex | |
| Control w/o Zn and Co | 0.18 | 0.54 |
| Zn 0.25 MAC | - | 0.80 |
| Zn 0.50 MAC | - | 1.06 |
Zn 0,75 MAC - 1,33
Zn 1,00 MAC - 1,59
Co 0,25 MAC 0,28 -
Co 0,50 MAC 0,39 -
Co 0,75 MAC 0,50 -
Co 1,00 MAC 0,61 -

Figure 1. Mathematical modeling of the connection of doses of a) Zn (kg/ha) with the content of mobile Zn (mg/kg); b) Co (kg/ha) with the content of mobile Co (mg/kg) in soil (“bxy”) of the fallow field and flax. Field experiments 2015-2018.

When modeling the connection in the system: “fertilizers (Co, kg/ha) → soil (W mg/kg)” - the content of mobile Co in soil had the same pattern as for zinc. When identifying Co in soil of the fallow field, the content of mobile Co was slightly higher (U1, “bCo”) - 0.028 mg/kg) than in the cultivation of flax (U2, “bCo” - 0.025 mg/kg) - equations (5 - 6).

\[ U1 = 0.028X1 + 0.24 \quad r = 0.99; \]  
\[ U2 = 0.025X2 + 0.18 \quad r = 1.00; \]

Equations 5 and 6, table 1 and figure 1 identify that each kg of applied cobalt to soil increases the content of mobile Co in soil (“bCo”) by an average of 0.0265 mg/kg of soil (0.028 mg + 0.025 mg)/2 = 0.0265 mg/kg. Studies show that 1 mg of Co/kg of soil corresponds to an equivalent amount of cobalt on average - 38 (1/0.0265 mg/kg).

4. Conclusion

Thus, having the coefficients of activity of each kilogram of Zn and Co on the content in soil of mobile zinc “bZn” - (0.013 + 0.012)/2 = 0.0125 mg/kg and cobalt “bCo” - (0.025 + 0.028)/2 = 0.0265 mg/kg, the best doses of zinc (60.6 kg/ha) and cobalt (12.8 kg/ha) were obtained on the basis of field experiments. Further, by the method of mathematical analysis, it is possible to establish the optimal levels of the content of mobile forms of Zn and Co in the soil using formula 7:

The equation of optimal balance:

\[ C_{opt} = C1 + D \ast b, \text{ mg/kg} \]  

Prediction of optimal levels of mobile zinc and cobalt in soil, mg/kg; Formula (3) is the best dose of Zn 60.6 kg/ha; Znopt, mg/kg = 0.0125 of Zn 60.6 kg + 0.585 = 1.34 mg of Zn/kg of soil; The actual zinc content in soil is 1.34 mg/kg;
Formula (4) is the best dose of Co 12.8 kg/ha; 
\[ \text{Co}_{\text{opt}}, \text{mg/kg} = 0.0265 \times 12.8 \text{ kg} + 0.21 = 0.55 \text{ mg of Co/kg of soil}; \]

The actual cobalt content in soil is 0.54 mg/kg.

Where - \( C_{\text{opt}} \), the optimal content of micronutrients in soil, mg/kg; 
CI - the actual content of Zn and Co in soil, mg/kg; 
D - the dose of optimal application of Zn and Co to soil, kg/ha; 
b – the coefficient of activity of the unit of application of Zn and Co on the chemical composition of soil, mg/kg.

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