Mathematical models for predicting the level of potatoes nutrition from the soil chemical composition in the Northern Kazakhstan conditions

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Abstract. The authors of the article presented a visual technique for programming the yield of potato tubers by using mathematical models of the relationship with the chemical composition of the soil. The content of N-NO₃ and P₂O₅ varied in the range of 14.7-35.0 mg/kg and 37.1-39.0 mg/kg of soil. The increase in the content of these nutrients was accompanied by an increase in the productivity of potato tubers from 1 ha. The results of the study showed that the yield value is closely related to the content of N-NO₃ and P₂O₅ in the soil in the initial phase of crop growth. The verification of the calculation methods showed a forecast error by comparing the actual yield data with the predicted results. The established quantitative indicators with the help of mathematical communication models make it possible to diagnose the value of potato yield and normalize the effect of fertilizers.

1. Introduction
The optimal conditions for the mineral nutrition of plants depend on the degree of soil supply with nutrients and the associated additional application of nutrients and fertilizers. Field trials, in which several increasing doses of each nutrient are tested, can be a reliable method for determining the optimal doses and ratios of mineral fertilizers [1, 2]. In addition to the use of fertilizers, literature sources track the effectiveness of various forms of seed treatments with plant growth stimulants [3, 4].

The cultivation of forage crops in the conditions of Northern Kazakhstan is associated with a large moisture deficit; it is required to program the crop by applying various doses of fertilizers.

Correction factors for average doses of fertilizers are widely used in practice, depending on the content of mobile nutrients in the soil [2, 5].

Potato is one of the staple crops of high technical and fodder importance. Every day all over the world, potato is used in many dishes as the main side dish or a part of other foods. In addition, potatoes are also valuable in agrotechnical terms. As a row crop, it helps to loosen the soil and clear the field of weeds. Cultivation of it after grain crops reduces the content of entomo- and phytophages in arable lands, which are harmful to cereals. High productivity, wide distribution, and environmental plasticity make potato a good insurance culture [1, 6, 7].
For increasing the volume of potato growing, plants need fertilizers in case of their relative deficiency or excess in the soil, the correct establishment of the optimal doses of fertilizers for a particular crop (variety) in specific weather conditions [5, 6, 7].

2. Statement of the problem
In connection with the intensification of production in agriculture and the development of a promising direction in agrochemistry - crop programming - more than 50 methods for determining the optimal doses of fertilizers for different crops have appeared. Each of the methods has its advantages and disadvantages, and, as practice shows, the problem of optimizing the mineral nutrition of plants does not have an unambiguous solution [2, 5, 8].

Balance methods are the most widely used in the practice of fertilizer doses [2]. They are based on data on the chemical composition of the soil (Eph), the consumption of nutrients to create a unit of production, the utilization rates of nutrients from the soil (URNS) and fertilizers (URNF), the fertilizer efficiency indicator (FEI), the value of the current nitrification (Nc).

3. Materials and methods
In our studies, ammonium nitrate, ammophos, and potassium chloride were introduced into thin chestnut soil with a light particle size distribution in the spring, followed by incorporation. The accounting area of the plots was 48 m$^2$. The analysis of soil samples was carried out using the equipment of the Center for Collective Use "Agrarian and Technological Research" and standard agrochemical methods. The plots were arranged in a randomized order. The experiment was carried out with potatoes of foreign selection "Gala".

Field experiments were carried out in 2015-2017 in LLP "Ushterek and K" of the Pavlodar region of the Republic of Kazakhstan. The experiments were repeated four times. The cultivation technique is generally accepted for the zone. Sowing and accounting of crop yields were carried out at the optimum time. The results of the study were processed by the method of variance of statistical analysis according to B.A. Dospekhov.

4. Discussion of the results
The levels of mineral nutrition of potatoes were identified by us with a systematic approach based on soil-plant operational diagnostics (SPOD). The article will consider mathematical models for predicting the power level of the developed diagnostic integration system.

The initial stage involves collecting primary information about the field on which the crop is planned to be sown (moisture reserves, precipitation) and other normative indicators necessary for calculating the level of RPY (real possible yield) according to the formula:

$$RPY = \frac{100 \cdot (W + O)}{Cwc \cdot S \cdot (100 - Hs)}$$

where RPY - real possible yield, T/ha; W – reserves of available soil moisture 0-100 cm, mm; O – amount of precipitation from May to August, mm; Cwc - water consumption coefficient; S - sum of the parts in relation to the main product to the secondary; Hs - standard humidity, %.

The second block of the SPOD system is based on soil analysis data.

Predicting the responsiveness of potatoes to applied fertilizers in specific soil conditions was one of the fundamental tasks of our research. The increase in yield does not occur indefinitely, but only up to a certain level of nutrient content in the soil and plants, above which there is a cessation of plant growth or even a decrease.

In this regard, it becomes necessary to standardize the content of chemical elements in soil and plants in certain natural conditions of crop cultivation. This allows you to control the production process, the formation of the size of the yield, and effective fertility.

Using mathematical methods, the relationship between the content of available nutrients in the soil and the yield of potatoes was established, which makes it possible to objectively evaluate the
experimental data of the chemical analysis of the soil, to diagnose the effectiveness of fertilizers, and to predict the yield.

The study of the relationship between the yield of potato tubers (average data for 2015-2017) and the content of nitrate nitrogen ($X_1$) and phosphorus ($X_2$) in layers of 0-30 cm made it possible to derive the equations of curvilinear regression (equations 1-2, Fig. 1-2):

\[
\begin{align*}
Y &= -0.0096x^2 + 0.6239x + 24.614 & \quad \eta = 0.97 \\
Y &= -3.2133x^2 + 247.54x - 4730.3 & \quad \eta = 0.98
\end{align*}
\]

The high correlation in both equations demonstrates the equivalence of data of chemical analysis of the soil in the 0-30 cm layer.

Figure 1. Nomogram of the dependence of potato yield ($Y$, t/ha) on the content of nitrate nitrogen ($X$, mg/kg) in the soil layer of 0-30 cm (parabola equations)

Figure 2. Nomogram of the dependence of potato yield ($Y$, t/ha) on the content of mobile phosphorus ($X$, mg/kg) in the soil layer 0-30 cm (parabola equations)
If we consider the influence of soil nutrients on the yield (Y, t/ha) of potatoes within the limits of the content of nitrate nitrogen (N) and mobile phosphorus (P), respectively, up to 32 mg/kg and 39 mg/kg, then there is a direct relationship between these parameters (equation 3-4):

\[
Y = 0.16N + 29.58 \quad r = 0.94 \quad (3)
\]

\[
Y = 1.61P - 28.75 \quad r = 0.67 \quad (4)
\]

Equations (3-4) obtained based on long-term average data indicate that with an increase in N-NO₃ and P₂O₅ in the soil by 1 mg/kg, and in the yield of potato tubers - on average by 0.16 t/ha and 1.61 t/ha, mathematical models make it possible to predict the value of potato yield depending on the content of nutrients in the soil (Fig. 3-4).

Figure 3. Nomogram of the dependence of potato yield (Y, t/ha) on the content of nitrate nitrogen (X, mg/kg) in the soil layer of 0-30 cm (direct dependence)

Figure 4. Nomogram of the dependence of potato yield (Y, t/ha) on the content of mobile phosphorus (X, mg/kg) in the soil layer of 0-30 cm (direct dependence)

These mathematical models make it possible to link the final result (yield value by years of research) with the current values (indicators of chemical analysis of nutrients in the soil) and make a
selection of mathematical models according to the year of cultivation and the varietal characteristics of the crop.

Equations 3-4 make it possible to predict the formation of the productivity of potato tubers depending on the content of the main nutrients in the soil (Table 1). By comparing the predicted results with the actual yield data, forecast errors are identified.

| Content, mg/kg | Productivity in fact | Forecasting the productivity of t/ha using the formulas |
|---------------|----------------------|--------------------------------------------------------|
|               | by N-NO₃ | by P₂O₅ | 3 (for N) | 4 (for P) | error, % | error, % |
| N-NO₃         | P₂O₅     | t/ha     | t/ha      | error, % | t/ha      | error, % |
| 14.7          | 37.1     | 31.7     | 30.7      | -0.63     | 31.0      | -0.98    |
| 20.7          | 39.6     | 33.4     | 33.4      | 1.5       | 35.0      | -4.79    |
| 32.2          | 39.1     | 34.7     | 36.6      | -0.29     | 34.2      | 6.56     |

The processing of the data of the chemical analysis of the soil, values of the yield of potato tubers from the applied fertilizers made it possible to determine the optimal levels of the content and ratio of nutrients in the 0-30 cm soil layer during the germination period. The levels for nitrogen were 32 mg/kg and for phosphorus - within 39 mg/kg of soil with the optimal ratio of P₂O₅ ≈ (1.22) · N-NO₃ ≈ 0.1 · K₂O.

5. Conclusion

Thus, taking into account the conditions of potato cultivation in specific chestnut soils of Northern Kazakhstan, the optimal content of N-NO₃ in the soil has the following regularity in a percentage ratio of 100 → 90, for P₂O₅ in the range of 100 → 85%. The establishment of optimal values and parameters, presented by the example of averaged long-term data, allow diagnosing the effectiveness of fertilizers and normalizing their application rates to the soil.

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References

[1] Abeuov S, Ermokhin Y, Shoykin O, Kamkin V 2019 Diagnosis of potatoes’ requirements for nitrogen fertilizers on chestnut soils of Northern Kazakhstan Advances in Social Science, Education and Humanities Research 393 455-458
[2] Ermokhin Yu I 1995 Soil-plant operative diagnostics "PROD-OmSHI" of mineral nutrition, fertilizer efficiency, size and quality of agricultural crops: Monograph (Omsk: OmGAU) 208 p
[3] Krasovskaya A, Veremey T, Stepanov A 2020 Effect of Pre-Sowing Seed Treatment on the Yield and Quality of Soybeans in the Subtaiga of Western Siberia The Fifth Technological Order: Prospects for the Development and Modernization of the Russian Agro-Industrial Sector (TFTS 2019) pp 421-424
[4] Chibis S, Krotova L, Beletskaya E 2020 Development of Spring Wheat Sprouts After Chemical Seed Treatment The Fifth Technological Order: Prospects for the Development and Modernization of the Russian Agro-Industrial Sector (TFTS 2019) pp 305-308
[5] Ermokhin Yu I, Krasnitsky V M 2000 Crop programming: Monograph (Omsk: OmGAU) 84 p
[6] Abeuov S K, Shoikin O D, Kamkin V A 2020 Influence of phosphoric fertilizers on the yield and quality of potatoes on chestnut soil Bulletin of the Omsk State Agrarian University 4(40) 15-23
[7] Bikkinina L, Ezhkov V, Prischepenko E, Yarullin M 2020 Impact of Multiple Forms and
Application Methods of Natural Zeolite on Potato Yield Increase *International Scientific Conference The Fifth Technological Order: Prospects for the Development and Modernization of the Russian Agro-Industrial Sector (TFTS 2019)* pp 114-118

[8] Cheremisin A, Khamova O, Dergacheva N, Tukmacheva E 2020 Assessment of the Effectiveness of the Use of Biological Products of Associative Nitrogen Fixation in Potato Cultivation *The Fifth Technological Order: Prospects for the Development and Modernization of the Russian Agro-Industrial Sector (TFTS 2019)* pp 371-375