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Determination of the soil equivalent in leached smolnitsa and alluvial-meadow soils by pot experiment

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Abstract

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Optimal fertilization rates can be determined based on an assessment of the nutrient content of the soil using crop production functions. Dependence between yield and the quantities in the soil (macro and microelements) is established through the construction of different mathematical models. The article aims to present a methodology for the determination of the so-called soil equivalent with the help of data from a greenhouse experiment conducted on two soils with contrasting properties, namely Leached Smolnitsa and Alluvial-meadow soils. All steps are given for the determination of soil equivalent of the factor potassium in experimental station Tsalapitsa. Confirmation of the effectiveness of the applied approach is illustrated with data from an archival field experiment.

Keywords: experimental design; fertilization; response function; soil equivalent

Introduction

The main objective of the current study is through experimental and theoretical activities to acquire new knowledge in order to develop the scientific basis of a new innovative method for optimal fertilization of agricultural crops. The existing scientific basis of the Automated system for agrochemical servicing of agriculture in Bulgaria needs to be updated and upgraded. In order to adapt fertilization recommendations to the rapidly changing production conditions and global climate problems, using the latest scientific and technological developments, it is necessary to constantly improve existing ones and to create new generations of models based on archive and qualitatively new information.

The dependence between yield and the quantities of nutrients in the soil (macro elements: N, P, K, Ca, Si, Mg, S, and Na; microelements: B, Mo, Zn, Fe, Mn, Cu, Co, Cl) is established through the construction of different mathematical models that describe sufficiently well the experimental data obtained in field and greenhouse (pot) trials. These mathematical models are often called production functions or response functions (Dillon, 1968).

The idea that optimal fertilization rates can be determined based on assessment of the nutrient content of soil using production functions was put forward by Anderson (1956). Derzhavin and Rubanov (1975) introduced the term soil equivalent for the quantity of the nutrient in the soil which is readily available to plants in a form, equivalent to the applied fertilizers. The soil equivalent can serve as an estimate of the soil fertility in the active ingredient of the applicable mineral fertilizers. Moreover, this assessment will be objective in the sense that it is obtained from the results of field or greenhouse experiments, which reflect the existing natural conditions in this area (Rubanov, 1978). The article aims to show a method for the determination of soil equivalent in two different soils by pot experiment.

Soil tests take the guesswork out of fertilization, are cost effective, and environmentally responsible. A soil test will provide an index of the amount of essential mineral nutrients available and recommend quantities of nutrients to apply. A soil test may reduce fertilizer costs, but will also eliminate over-usage of fertilizers, hence helping to protect the environment (Streich et al., 2014). Soil testing to estimate mineral nutrients in soil does not need to be done every year. But the problem to find the quantity which is readily available to plants in a form, equivalent to the applied fertilizers, still remains.

A similar term "sand equivalent" was introduced and used in material testing. The term "sand equivalent" expresses the concept that most fine aggregates are mixtures of desirable coarse particles (e.g., sand) and generally undesirable clay or plastic fines and dust (ASTM, 2003). Its determination is performed by laboratory-analytical methods.

Materials and Methods

The study used data from greenhouse experiments with two types of soils: Leached Smolnitsa from Bozhurishte and Alluvial-meadow soil from Tsalapitsa. The variants are 16 in 3 replications and pots with 3 kg of soil. The factors: nitrogen, phosphorus, potassium, and silicon in mg/pot, varied at 5 levels are presented in Table 1. The properties of the design and methods for analysis of data are described in publication (Sadovski, 2021b).

Table 1. The design with active substances of fertilizers, mg/pot

Variants	Factors			
	N	P	K	Si
1	0	0	0	0
2	0	160	140	800
3	400	160	140	800
4	200	0	140	800
5	200	320	140	800
6	200	160	0	800
7	200	160	280	800
8	200	160	140	0
9	200	160	140	2000
10	200	160	140	800
11	300	240	70	400
12	300	80	210	400
13	300	80	70	1200
14	100	240	210	400
15	100	240	70	1200
16	100	80	210	1200

A significant error in many of the known models is that the argument X on their right-hand side represents the introduced quantity of mineral fertilizer, without taking into account the quantity of nutrients already available in the soil.

This theory expresses the quantity of a given nutrient X as a sum of the initial level of the nutrient X_0 and the quantity introduced with fertilizers F:

$$X = X_0 + F \quad (1)$$

The quantity X_0 of the nutrient in the soil which is readily available to plants is the soil equivalent (Derzhavin & Rubanov, 1975). Knowing the required amount of nutrient substance to obtain a given yield and a soil equivalent, one can find the required amount of fertilizer to obtain a given yield. It will be determined as the difference between the required amount of nutrient substance and the soil equivalent (Rubanov, 1978).

Graphical presentation of the soil equivalent X_0 is shown in Figure 1.

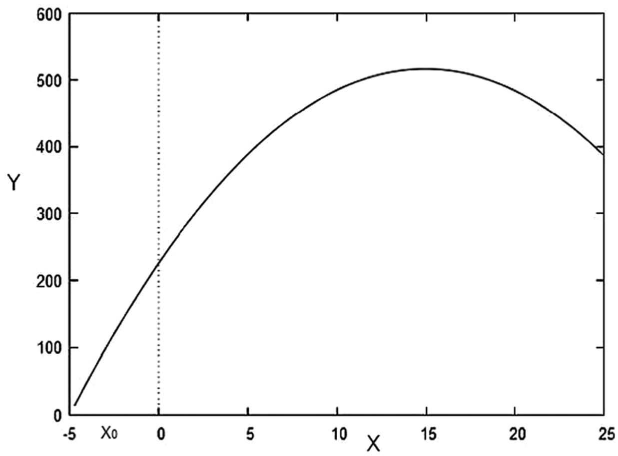

Fig. 1. Response function and soil equivalent

The main equation represents yield as an intrinsically non-linear function of macro element fertilization and has the expression (Sadovski, 2019; Sadovski, 2020; Sadovski, 2021a) with regression coefficients a, b and c:

$$Y = f(X) = a(X_0 + F)^b \exp[c(X_0 + F)]. \quad (2)$$

This multiplicative equation is a composition of a power function and an exponential function. Thus, it contains the mechanism of homeostatic feedback.

If the constant X_0 is known, then the other three parameters can easily be determined from the main equation (2) by applying a logarithm

$$\ln Y = \ln a + b \ln(X_0 + F) + c\,(X_0 + F). \quad (3)$$

An estimation of the soil equivalent X_0 is possible when the response function is approximated by a second-degree polynomial (Rubanov, 1978).

$$\underline{Y} = a_0 + a_1 F + a_2 F^2 \quad (4)$$

Then X_0 is the absolute value of the negative root of the quadratic equation with coefficients a_0, a_1, and a_2 (see Figure 1).

$$X_0 = \left| \frac{-a_1 + \sqrt{a_1^2 - 4a_0 a_2}}{2a_2} \right|. \quad (5)$$

It will be used to find the necessary amount of fertilizer to be applied.

Results

To estimate soil equivalents for the nutrients in selected soils it is necessary to have at least four experimental points with data for the factors and corresponding values of the dependent variable (e.g., height, weight of stems, and roots). To solve the problem selections of variants from the design are made (Tables 2 – 5), which contain the control variant No. 0, the minimal, mean, and maximal value of the determining factor (N, P, K, and Si) when other factors are fixed at their mean values (N = 200, P = 160, K = 140, Si = 800 mg/pot).

Here are given the steps for the determination of soil equivalent of the factor potassium in Alluvial-meadow soil (Tsalapitsa). First, the approximated second-degree polynomials for the height, weight of stems, and roots were found:

$Y_h = 70.295 + 35.484*F - 10.226*F^2$;
$Y_{stems} = 80.50 + 94.205* - 26.895*F^2$;
$Y_{roots} = 29.235 + 23.079*F - 7.0106*F^2$.

Corresponding absolute values of the negative roots of quadratic equations are:

X_0(height) = 98.61, X_0(stems) = 49.73 and X_0(roots) = 68.21.

The mean of the obtained three values is the required value of potassium soil equivalent (equal to 72.18 mg/pot)

Table 2. Data to determine soil equivalent for nitrogen, mg/pot

Variants	Factor	Tsalapitsa			Bozhurishte		
	N	h, cm	stems, g	roots, g	h, cm	stems, g	roots, g
1	0	47.42	24.33	10.40	87.00	90.00	33.11
2	0	53.17	31.33	10.67	84.25	95.00	21.93
3	400	99.33	157.33	33.13	99.00	230.00	42.93
10	200	100.33	161.33	46.97	104.25	213.67	44.54

Table 3. Data to determine soil equivalent for phosphorus, mg/pot

Variants	Factor	Tsalapitsa			Bozhurishte		
	P	h, cm	stems, g	roots, g	h, cm	stems, g	roots, g
1	0	47.42	24.33	10.40	87.00	90.00	33.11
4	0	98.25	158.00	55.35	99.00	200.00	43.09
5	320	97.92	150.67	47.78	103.00	196.70	43.43
10	160	100.33	161.33	46.97	104.25	213.67	44.54

Table 4. Data to determine soil equivalent for potassium, mg/pot

Variants	Factor	Tsalapitsa			Bozhurishte		
	K	h, cm	stems, g	roots, g	h, cm	stems, g	roots, g
1	0	47.42	24.33	10.40	87.00	90.00	33.11
6	0	93.17	136.67	48.07	102.50	199.00	40.65
7	280	48.50	27.00	7.86	104.75	225.33	46.20
10	140	100.33	161.33	46.97	104.25	213.67	44.54

Table 5. Data to determine soil equivalent for silicon, mg/pot

Variants	Factor	Tsalapitsa			Bozhurishte		
	Si	h, cm	stems, g	roots, g	h, cm	stems, g	roots, g
1	0	47.42	24.33	10.40	87.00	90.00	33.11
8	0	85.92	144.33	42.67	99.50	207.00	44.30
9	2000	95.17	148.33	44.61	98.75	153.00	40.96
10	800	100.33	161.33	46.97	104.25	213.67	44.54

Table 6. Soil equivalents in two soils, mg/pot

Nutrient	Tsalapitsa	Bozhurishte
Nitrogen	56.81	197.81
Phosphorus	93.79	505.36
Potassium	72.18	305.94
Silicon	581.03	1163.68

After approximating the second-degree polynomials for all factors and dependent variables (nutrients), we obtain the values of the soil equivalents for both soils (Table 6).

It is evident that the Leached Smolnitsa in Bozhurishte is better stored with the four nutrients than the Alluvial-meadow soil in Tsalapitsa.

To confirm the effectiveness of the applied approach, it is illustrated with data from a former field experiment of the Poushkarov Institute.

Example. Finding soil equivalent from a field experiment with wheat in 1968.

An excerpt from the data of yield at the experimental station Alvanovo, Targovishte district was used (Yearbook, 1971). The experiment was performed according to the scheme 4x4x3 (nitrogen 0, 12, 18, 24; phosphorus 0, 8, 16, 24; potassium 0, 12, 24 kg/da). Data on phosphorus variation were calculated at a fixed level of nitrogen (N = 18 kg/da) and potassium (K = 0 kg/da). Corresponding regression equation was found

$$Y = 344.397 + 8.7996*F - 0.2291*F^2. \quad (6)$$

According to the formula (5), a value of the soil equivalent X_0 = -24.062 is obtained, which means that 24 kg/da phosphorus is readily available to plants in a form, equivalent to the applied fertilizers.

Using the obtained value of X_0 with the help of equation (3) we can find the constants of the equation:

a =10.3828, b = 1.32633, c = -0.02962.

The resulting transcendental function has the form

$$Y = 10.3828(24.062 + F)^{1.3263} e^{(-0.02962*(24.062+F))}. \quad (7)$$

From here the values of phosphorus to be applied for reaching the maximum yield is obtained $F_{max} \approx 21$ kg/da.

Conclusions

The new quantity - soil equivalent, is discussed with the help of which it is possible to estimate the quantity of the nutrient in the soil which is readily available to plants. The presented examples from the pot experiment conducted with two soil types with contrasting properties confirm the theoretical meaning and practical benefit of using the soil equivalent. A confirmation of the effectiveness of the applied approach is presented with data from an archival wheat experiment (dated 1968) of "N. Poushkarov" Institute.

The proposed quantity soil equivalent allows solving several problems of agrochemical service of agriculture and reducing the cost of additional field experiments with fertilizers to assess their effectiveness. Another perspective for research is to establish the correlation between calculated values of the soil equivalent and results from laboratory analyses of the same soils regarding the content of nutrients available to plants.

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