Mathematical Modeling of the Relation between Basic Chemical Elements and Soil Properties

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***Abstract* – This paper presents mathematical modeling of the relation between basic chemical elements and soil properties. An overview of the basic chemical elements and properties of the soil is presented. An approach is proposed to conduct an experimental study of the impact of basic chemical elements and soil properties. Statistical methods are used for data processing. Mathematical models for relation between basic chemical elements and soil quality indicators are developed. Mathematical models for indirect determining the content of basic chemical elements by measuring the main soil indicators are analyzed.**

***Keywords* – Chemical soil elements, Soil indicators, Soil conductivity, Statistical methods, Mathematical models.**

1. Introduction

Plants produce important nutrients such as carbohydrates, proteins, sugars, fats and vitamins by taking simple raw materials such as carbon dioxide, air, water and minerals. These substances are produced in the green leaves through sunlight, green leaf substance (chlorophyll), water and nutrients. Nutritional elements are needed for growth, photosynthesis and plant growth. Each vital nutrient has its function in the body of the plant.

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The need for a particular nutrient can only be satisfied by supplying the plant with that particular element. In the case of deficit of nutrients, it is not possible to choose any kind of mineral fertilizer. It should be chosen according to the nutrient content [3].

When the concentration of a nutrient element falls below the critical level, the plant begins to suffer from a deficiency of this element. This interferes with its vital functions. Symptoms of deficiency begin to manifest on different parts of the plant. If these symptoms are at an early stage, getting the plant with the necessary nutrient returns the process and the symptoms disappear. However, a severe form of shortage is not completely reversible. The role and the various symptoms of deficit of different nutrients is:

Nitrogen (N): Nitrogen in nitrogenous organic compounds found in plants is always in a reduced form in the form of oxygen-free clusters, linked to carbon atoms by the molecules of the compounds. This means that when plants feed on nitric (oxidized) nitrogen before becoming a constituent of plant organic compounds, it must be reduced.

Nitrogen is present in large quantities in nature, occupying about 75% of the mass of the atmospheric air. In the construction of the plant organism it occupies the fourth place after carbon, oxygen and hydrogen - about 4.3% of the dry matter. Nitrogen is included in all protein compounds, amino acids, nucleic acids, phosphatides, chlorophyll, some alkaloids and glucosides. Because of the particular biochemical and chemical properties of this element, in most cases soils are poorly stocked with digestible nitrogen forms [1]. It is part of chlorophyll and all proteins. Cause for the dark green color of the stem and leaves, vigorous growth, branching, leaf formation and growth. Plant growth stops when it stops being supplied with nitrogen. Plants suffering from nitrogen deficiency are stunted and yellowish. The yellowing appears first on the lower leaves. In a severe form of deficit the leaves become brown and die [2]. Yields and protein content decrease. Nitrogen deficit can cause a dead end process at the end of the leaves, a predisposition to certain diseases, an increased risk of "pollination" (in cereals), and poor yields [5].

Phosphorus (P): Phosphorus is a major macro-element needed for plant nutrition. The phosphorus participates in metabolic processes such as photosynthesis and synthesis, as well as carbohydrate degradation.

Regardless of the form (organic or mineral) of phosphorus in the soil, its solubility is low. There is a balance between phosphorus in the solid phase of the soil and phosphorus in the soil solution. Plants can only absorb phosphorus dissolved in the soil solution, but most of it exists in stable chemical compounds, and only a small fraction is available to plants for absorption at any moment [4]. When the plant roots extract the phosphorus from the soil solution, part of the amount adsorbed to the solid phase is released again into the soil solution - thus maintaining equilibrium.

Phosphorus is found in the soil, both in organic and in mineral form. Nevertheless, the amount of available phosphorus is very low compared to the total amount of phosphorus in the soil. That is why, in many cases, it is necessary to use phosphorous fertilizers in order to protect the needs of the plants.

It is vital for growth, cell division, root development, seed and fruit, and early maturation. It is part of several compounds including fat and amino acids. Phosphorus compounds supply the plant with energy. The deficiency of phosphorus causes growth retardation, root growth and maturation.

Potassium (K): Potassium accounts for about 2.5% of the earth's crust, making it the seventh most common element there. Because of its affinity to associate with other elements, it does not occur in its elementary form. The ability of the soil to naturally supply plants with potassium depends mainly on mineralization processes.

There are several factors that influence the absorption of chemical elements in plants such as climatic, geochemical and biological factors [8].

It is necessary for the action of more than 60 enzymes, the accumulation of nutrients from the photosynthesis, the storage of water and the provision of resistance against a number of pests, diseases and harmful climatic influences.

Models for balanced application of fertilizers (nitrogen, phosphorus and potassium) have been developed [7]. The results show that when N, P, K reach 372.83 kg/ha, 89.65 kg/ha, 201.41 kg/ha (N: P_2O_5: K_2O = 1: 0.240: 0.540), the maximum value is 19.09 kg/ha, eligibility reached 84.95%. These models show the influence of the amount of chemical elements and soil pH on the degradation of glucuronanine and glucosinolates (GS) [7]. The disadvantage of these models is that the electrical conductivity of the soil is not included in the model. The soil composition is a very important and influences the nutrients in the soil, which affect plants [9].

2. Measuring of basic soil chemical elements and properties

Soil analysis kit MT 6003 which allows measuring the concentration of the three basic chemical elements nitrogen, phosphorus and potassium in a soil sample (Fig. 1.) is used.

The subject of the research is a peat-soil substrate with a defined nitrogen, phosphorus and potassium content for indoor and garden plants.

The soil substrate is divided into five pots in which a liquid fertilizer is placed with different proportions of the basic chemical elements of the soil - nitrogen, phosphorus and potassium. Liquid fertilizers are selected because they are easily absorbed from the leaves of plants, especially in dry periods, when fertilizers can be more effective. It is possible to reduce the evaporation of droplets and to reduce atmospheric pollution by adding liquid fertilizers. Emission of nitrogen into the soil, which is extremely important for protected water areas, is eliminated.

In the experimental study, liquid combined fertilizers series Fast and Fast + were used.

Liquid compound fertilizers of the Faust series are a complex of macro-nutrients in optimal proportions to suit all plant needs. In combination with the macro-elements, a complex of chelated micro-nutrients is included, which implies their seamless absorption by the plant. The formulas presented in the series are NPK 10:10:10, NPK 6:12:12, NPK 5:15:10 and PK 16:16. In this way, these products enable farmers to fully nourish plants with liquid fertilizers, thus providing them with easily accessible and digestible food at any time of vegetation.

Liquid compound fertilizers of the FaST + series are a complex of microelements in optimal proportions, meeting the needs of individual crop groups during vegetation.

Liquid fertilizers are a crystal clear product, combining the essential nutrients - nitrogen, phosphorus and potassium, and trace elements (B, Cu, Fe, Mn, Mo and Zn). Suitable for basic and corrective fertilization. Their composition includes a certain percentage of the major chemical elements. For example, NPK 10:10:10 liquid fertilizer includes:

- total nitrogen content (N) - 10%;
- diphosphorus pentoxide (P_2O_5), water soluble - 10%;
- dipotassium oxide (K_2O), water-soluble - 10%.

After fertilization, the main indicators of soil condition - pH, electrical conductivity and humidity, as well as its basic chemical elements are measured.

The obtained results are analyzed by statistical methods, determining the correlation between the basic chemical elements and the indicators; models are developed and evaluated to determine the basic chemical elements of the various indicators and the experimental accuracy of the developed models is established.

The soil sample analysis procedure includes the following steps:

- a sample of the soil to be analyzed is taken;
- place in a tube to 7.5 mL pre-filled with MT 5015 extraction solution;
- the soil solution is stirred for one minute;
- extraction stays for 5 minutes, precipitates;
- individual nitrogen, phosphorus and potassium tests are carried out by taking 2.5 mL extraction liquid and placing it in a clean tube, adding the reagent corresponding to the chemical element, shaking for 30 seconds to dissolve the reagent, and after 5 minutes, the color of the resulting liquid sample is compared with the color map for the corresponding chemical element.

Figure 1. Soil kit for measuring the concentration of the three basic chemical elements nitrogen, phosphorus and potassium in a soil sample

For the experimental study, a system has been designed whose circuit consists of a microcontroller that provides the information needed by the sensors to process it appropriately and provides it for visualization and storage in the memory; a power supply unit that serves to power the microcontroller. The remaining blocks are connected to the power terminals of the microcontroller board; soil acidity sensor; a soil salinity measurement sensor and a soil humidity sensor. A graphical user interface has been developed to visualize and store the measured parameter values on a personal computer.

- *Microcontroller Arduino Uno*

The technical characteristics of the microcontroller shown in Figure 2. are:

-Microcontroller: ATmega328P;
-Operating voltage: 5 V;
-Digital I / O port: 14 (of which 6 may be PWM outputs);
-Analog inputs: 6;
-Maximum I / O port current: 40 mA;
-Progressive memory: 32 KB, of which 0.5 KB occupied by the bootloader;
-SRAM: 2 KB;
-EEPROM: 1 KB.

One of the advantages of Arduino as a platform is its availability for Windows, Linux and MacOS X.

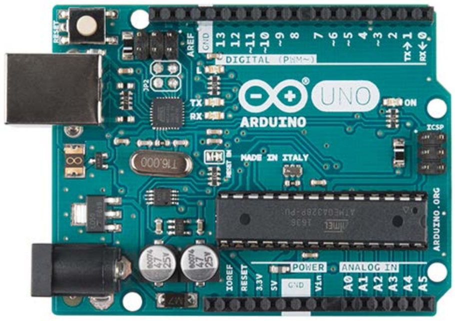

Figure 2. Microcontroller Arduino Uno

- *Sensor for pH measurement*

The technical characteristics of the pH sensor (Fig. 3.) are:

-pH Range: 0-14 (Na+ error at >12.3 pH);
-Speed of Response: 95% in 1 second;
-Isopotential point: pH 7.00 (0 mV);
-Offset: +/- 0.20 pH;
-3 buffer solutions and storage solution;
-38 400 baud rate default.

Figure 3. PH sensor and its calibration solutions

Figure 3. shows the calibration solutions of the pH and the sensor. The solutions are:\
-125ml Red Buffer Solution - pH 4.0;
-125ml Yellow Buffer Solution - pH 7.0;
-125ml Blue Buffer Solution - pH 10.0;
-125ml Storage Solution.

- *Sensor for measuring electrical conductivity*

The technical characteristics of the electrical - conductivity meter [6] presented in Figure 4. are:

- Measuring Surface: Platinum black coated platinum;
- Max Temperature: 0-70 ^{o}C;
- Conductivity readings +/- 2μs/cm;

- Full Conductivity range from 0.55 µs/cm to 500,000+ µs/cm.

Figure 4. Sensor for electrical conductivity measurement and its calibration solutions

- *Soil Moisture Sensor*

The Soil Moisture Sensor is a simple breakout for measuring the moisture in soil and similar materials. The soil moisture sensor is pretty straight forward to use. The two large exposed pads function as probes for the sensor, together acting as a variable resistor [6].

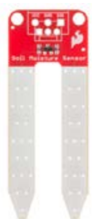

Figure 5. Soil moisture sensor

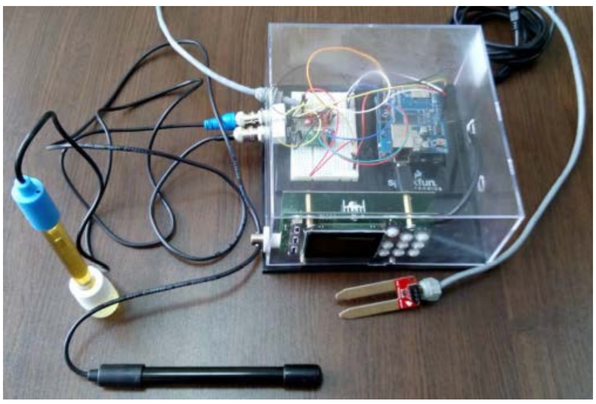

Figure 6. Wireless system for measuring pH, electrical conductivity and soil humidity

3. Results

The mean values of the measurements for the main indicators and chemical elements are presented in Table 1.

Table 1. Mean values of measurements for main indicators and chemical elements

Fertilizer	pH	EC, S/cm	M, %	N	P	K
16:16	5,1	171,1	50,4	20,0	100,0	525,0
6:12:12	4,9	233,7	43,6	15,0	100,0	200,0
5:4,5:8	5,1	174,7	47,8	15,0	30,0	112,5
5:15:10	4,7	214,4	53,0	15,0	100,0	200,0
10:10:10	4,7	374,3	51,8	30,0	70,0	200,0

To convert the color map level for the three basic chemical elements, the following values are used in Table. 2.

Table 2. Color map levels for the three basic chemical elements and numerical values

Level	N	P	K
Trace	<10	<20	<75
Low	10-20	20-40	75-150
Medium	20-30	40-100	150-250
High	>30	>100	250-800

In Table 3. the correlation coefficients are presented in the study of the dependence of the basic chemical elements and the main indicators of the soil.

The results obtained show that nitrogen has a strong dependence on conductivity, phosphorus - a significant dependence on the acidity indicator, and potassium - a moderate dependence on the acidity indicator.

Table 3. Correlation coefficients of the dependence of the main chemical elements and the main soil indicators

	pH	EC	Moisture
N	0,366713822	0,830438111	0,4370447
P	0,56860944	-0,00930641	0,06943827
K	0,338510547	-0,28646209	0,20271505

Determining the confidence interval depends on the distribution of the random quantity and the probability. Figure 7. shows the effect of the chemical element nitrogen on soil pH. The confidence interval is 0.95 and indicates that nitrogen influences the pH of the soil.

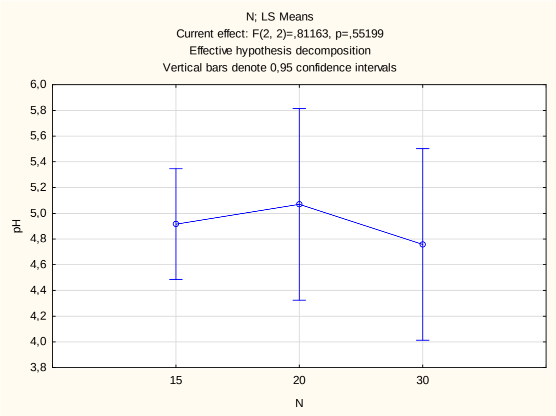

Figure 7. Influence of the chemical element - nitrogen on soil pH

Figure 8. shows the influence of the chemical element phosphorus on soil pH. The confidence interval is 0.95 and indicates that phosphorus affects the pH of the test soil. Figure 7. shows the influence of the chemical element potassium on the pH of the soil. The confidence interval is 0.95 and indicates that potassium has an effect on the pH of the test soil at a higher concentration.

From the comparison of the confidence intervals in Figures 7., 8. and 9., it follows that the chemical elements - nitrogen, phosphorus and potassium affect the pH of the soil.

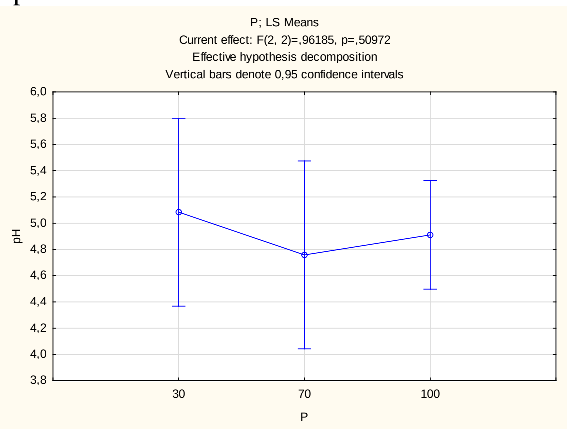

Figure 8. Effect of the chemical element - phosphorus on soil pH

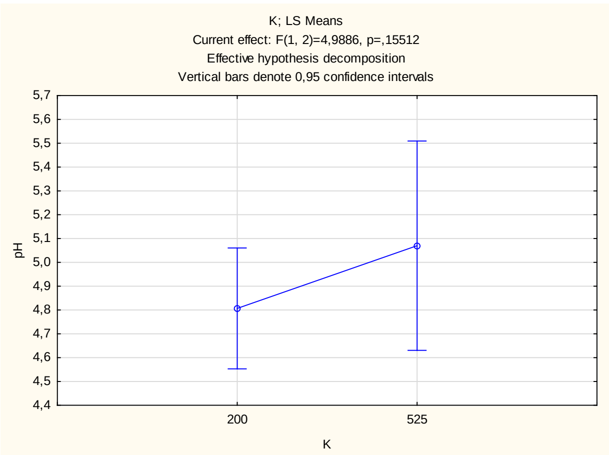

Figure 9. Effect of the chemical element - potassium on soil pH

An adequate model is a model of the appropriate order whose determinant is close to one. This factor shows what percentage of the scatter of the resulting result variable is explained by the action of the factor.

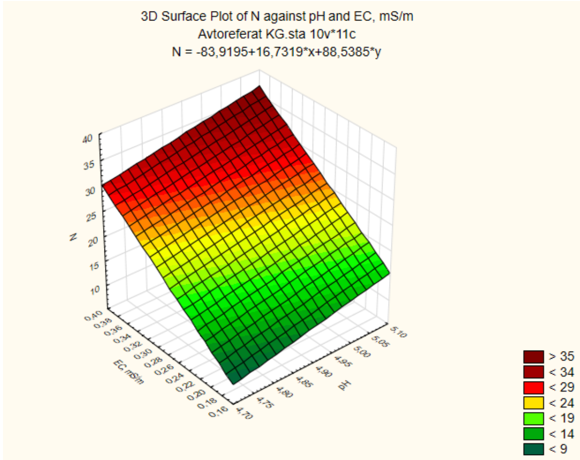

Figure 10. Linear model for indirect nitrogen determination

The model for function N =f(pH, EC) is:

$$N = -83{,}9195 + 16{,}7319 * pH + 88{,}5385 * EC$$ (1).

The lines of equal response (Fig. 11.), show that the chemical element nitrogen has a greater influence on the soil pH than on the electrically conductive soil.

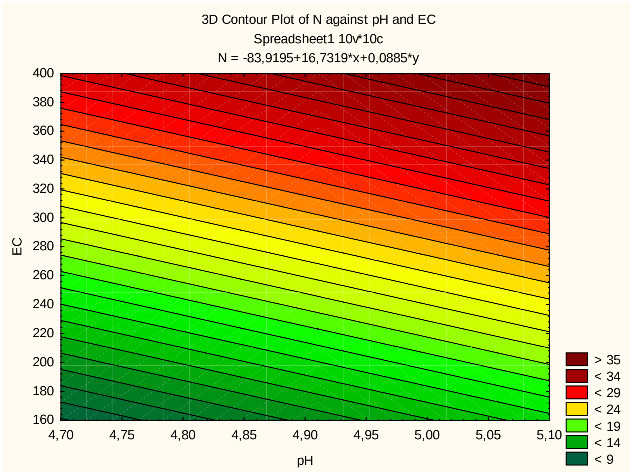

Figure 11. Lines of equal response *N=f(pH,EC)*

The model for the phosphorus is:

$$P = 770{,}0717 - 131{,}5386 * pH - 0{,}1866 * EC$$ (2).

From the lines of equal response shown in Figure 13., it can be seen that the chemical element phosphorus has little influence on the pH and the electrical conductivity of the soil.

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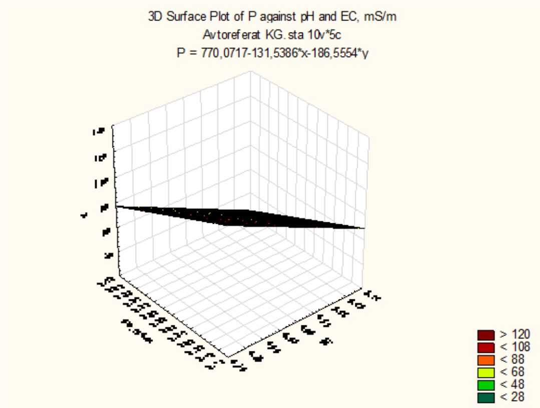

Figure 12. Linear model for indirect phosphorus determination

The model for potassium is:

$$K = -998{,}1386 + 262{,}2983 * pH - 186{,}2079 * EC \quad (3)$$

Figure 15. shows the same response lines showing that the chemical element potassium influences the pH and the electrical conductivity of the soil.

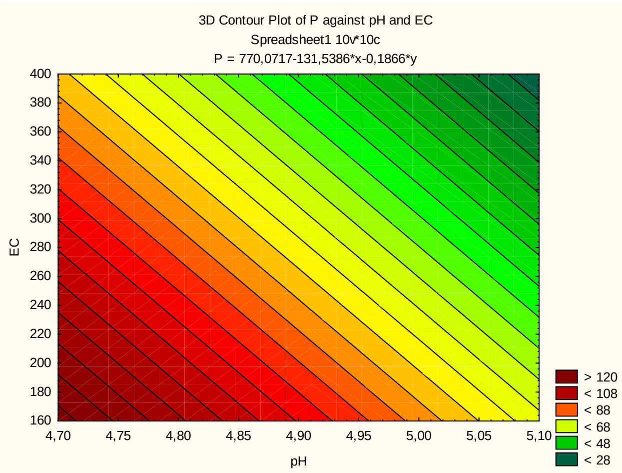

Figure 13. Lines of equal response P=f(pH,EC)

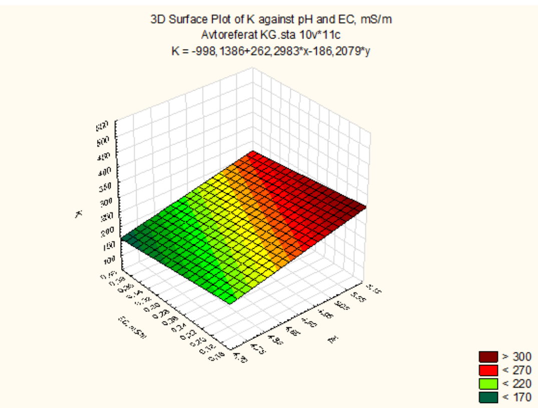

Figure 14. Linear model for indirect potassium determination

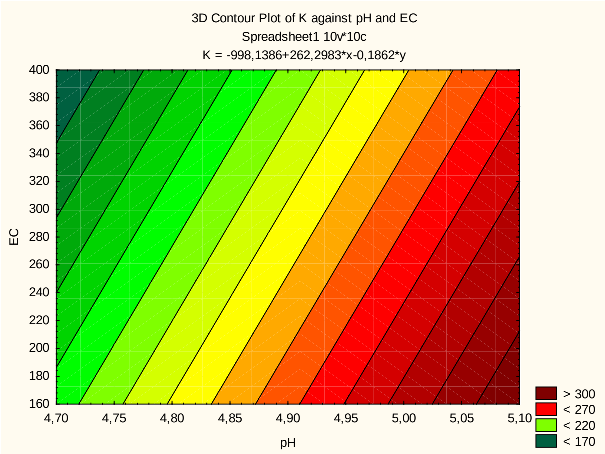

Figure 15. Lines of equal response K=f(pH,EC)

4. Conclusion

In the experimental study, a turf-soil substrate with a defined nitrogen, phosphorus and potassium content for house and garden plants was used. Liquid combined fertilizers of the FAST NPK series 10:10:10, NPK 6:12:12, NPK 5:15:10 and PK 16:16 were used.

The pH and power conductivity values were measured by designing and developing a wireless system to monitor the main soil quality parameters.

A chemical test was conducted to determine the amount of nitrogen, phosphorus and potassium in the soil.

Models are developed for indirect determining the content of basic chemical elements by measuring basic soil indicators.

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