On the possibility of conducting fast and reliable soil tests

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Summary: *The current interest in soil awareness is largely due to the increased importance of growing crops in a changing climate. It is characterized by prolonged droughts, followed by short but intense rainfall, often accompanied by strong winds and low temperatures. In a number of situations and due to insufficient information about the condition of the soil and the applied technologies for its treatment, the latter is not able to absorb rainwater, surface water runoff is formed, which exports large amounts of fertile soil and nutrients. An innovative approach is proposed to perform fast and accurate soil tests using its electromagnetic conductivity. A number of physical, chemical and biological properties can be determined by this method.*

Keywords: CLIMATE CHANGE, TILLAGE TECHNOLOGIES, SOIL PROPERTIES, ELECTROMAGNETIC CONDUCTIVITY.

1. Introduction

Preservation and increase of soil fertility is a set of application of modern agricultural practices, expressed in technological activities for tillage, hydro-ameliorative measures, optimal fertilization with mineral and organic fertilizers and use of pesticides, and return to the soil of organic waste processed mechanically or composted, etc., [36].

A significant part of the soils in Bulgaria are affected to varying degrees by degradation processes, which include all types of soil erosion, acidification, salinization, pollution, destruction, etc., which reduces the ability of soils to absorb carbon and increase greenhouse gases from unsuitable agricultural activities. All arable land is characterized by increased mineralization of soil organic matter, which is why it is recommended to apply annual organic materials (by plowing, manure, compost, etc.) in order to enrich the soil with highly active humic substances directly related. to plant nutrition.

The reduction of nutrients in the soils of arable lands is associated with the removal of the surface soil layer due to erosion, oxidation of organic carbon from areas with intensive cultivation, improper farming techniques, degradation of soil structure during soil compaction and others. Their rational use is the result of properly applied technologies for growing crops, optimized plant nutrition, efficient use of available water resources and more. To this end, it is necessary to have sufficient and reliable information on the condition of the soil, [2,3,15].

As a result of complex chemical and biochemical processes, a significant part of the organic matter from plant and animal residues that has entered the soil is transformed into specific organic matter with a complex structure, digestible for plants, etc. hummus. Humic substances are concentrated in the one-meter soil layer. The amount and composition of soil organic matter (OM) depends on the climate, microbiological activity and the composition of the humicizing materials.

Current soil health tests and the indicators included in them vary from laboratory to laboratory and there is currently no consensus on which basic biological measures should be included in a comprehensive soil health test, [8].

Finding a widely applicable, relatively inexpensive, convenient, but scientifically stable test for soil health, which is also related to the sustainability of yields, is a challenge for the scientific community, [8,10,11].

On the eve of the fourth industrial revolution and in the conditions of intensively developing digital technologies, agriculture also became an environment for their application. The capabilities of these new technologies provide the farmer with solutions that make it possible to ensure and maintain a balance between conserving natural resources and meeting the needs of the rapidly growing population of the planet for quality food and raw materials for industry, [1].

The system for the application of digital technologies in agriculture must be developed on a top-down basis and implemented 'bottom-up'. In this way, and with their help, farmers could be successful despite their differences in knowledge and experience. Even a novice farmer can quickly become successful in his business, something that his other colleagues have achieved after many years of experience and in which they have often relied on the method of "trial and error", [23, 25].

The basis of the majority of digital technologies in agriculture is the use of proven by science and practice simulation models, describing separately or in combination various physical, mechanical, biological and other processes occurring in the cultivation of crops, [6]. In this way, agricultural technologies can become proactive, ie. they should react in a timely manner to changes in the conditions of their implementation and to anticipate the expected end result. The sustainability of such technologies largely depends on maintaining a constant connection with the environment of their application. Simulation models, in addition to being the result of this connection, can be adapted to processes and phenomena that appeared at a later stage of their creation as a result of changes in the factors influencing the object of impact, [6, 36,38] .

Proactive technologies provide different opportunities for decision-making at each stage of their implementation, ie. at any stage of plant development or the state of the resources used. Therefore, a successful solution will depend on the correct application of good practices in the individual stages, [12,14].

EU requirements are for mutual adherence to good agricultural practices. If the requirements are not met, farmers run the risk of losing payments under the various programs. EU rules alone are not enough to solve the problem, as farmers in the region (and not only in the region) do not clearly understand how to apply such technologies.

The main reason for the unclear and partial application of digital technologies stems from the lack of understanding of farmers about how such technologies work and can complement each other so that they are useful in practice. Their misunderstanding is often accompanied by the expression: "This is too complicated„ ". Farmers focus mainly on short-term results and do not pay much attention to long-term ones. Current agricultural practices are affected by wrong incentives, lack of sufficient training and modern knowledge.

It is important to note that in Bulgaria consulting services cannot fully provide expert advice on innovations in the application of technologies in agriculture. Usually the advice that Bulgarian farmers receive regarding innovations is based on foreign experience and products, which for the most part have not been proven for the conditions in Bulgaria.

2. Materials and method

There are three main groups of indicators that determine the health of the soil. These are the groups that reflect their physical, chemical and biological properties. Each of them contains several indicators that interact and each of them affects the properties of the others [9,13,16], Fig.1.

Figure 1. Interaction between the main groups of soil properties

The predominant part of these indicators can be determined with modern means for analysis and digitalization.

Their determination shows the complex condition of the soil, also called "soil health". There is currently no consensus among the scientific community as to which indicators are key in the individual groups and which are their derivatives.

Current soil tests are relatively expensive, vary from laboratory to laboratory, and show inconsistent management results and practices.

Additional research is needed to calibrate and validate all soil health indicators, as well as innovative methods of analysis. This is especially true for biological indicators.

The ideal test for soil condition should be:

• widely applicable to all types of soils and at any time;

• sensitive and adaptive to different cultures management practices;

• reliable in relation to the submitted information;

• adaptable to the methods of digital technologies in order to filter and present the analyzed information for different groups of users.

A good soil health test should be convenient for the farmer to be able to take a sample, perform a measurement and obtain the final result. A number of measurements to determine physical quantities usually have to be made in the field, and some using special equipment.

One of the significant measurements that can be used as an indicator of soil fertility and to digitize it is its electrical conductivity, [19,21,27,29,33].

Soil electrical conductivity (ECa) is a measurement that correlates with soil properties that affect crop productivity, including soil texture, cation exchange capacity (CEC), drainage conditions, organic matter level, salinity, soil characteristics. the individual layers of the soil, the presence of nutrients, etc ..

The current flow in determining the ECa in the soil passes through three media:

(i) liquid phase medium. It contains dissolved solids contained in groundwater. The liquid medium occupies the large pores;

(ii) solid-liquid phase medium. These are mainly through exchange cations associated with clay minerals, [20,22,24,28,44];

(iii) medium of solid soil particles that are in direct and continuous contact with each other (Rhoades et al., 1999a), [41,42,43].

Due to the presence of the three conduction media, the measurement of ECa is influenced by several physical and chemical properties of the soil, such as soil salinity, cation saturation rate, water content and bulk density, [13, 29,45].

The percentage of saturation and bulk density are directly influenced by the content of clay and organic matter (OM). In addition, the exchange surfaces on clays and OM provide the medium of the solid-liquid phase mainly by exchange cations. Therefore, the content and type of clay, cation exchange capacity (CEC) and OM are recognized as additional factors influencing ECa measurements. ECa measurements should be interpreted taking into account these influencing factors.

Another factor influencing ECa is temperature. Electrolyte conductivity (EC) increases by approximately 1.9% per 1◦C temperature rise. EC is usually expressed at a reference temperature of 25 ° C, [16,46].

Studies show that the optimal values of ECa for fertile soils should be in the range of 110 - 570 millisiemens / meter (mS / m), [18,47].

High ECa values indicate the presence of negatively charged particles (of clay and organic matter) and therefore the presence of more cations (which are positively charged) and are retained in the soil. These are the cations of sodium (Na +), ammonium (NH4 +), potassium (K +), calcium (Ca2 +), magnesium (Mg2 +), hydrogen (H +), iron (Fe2 +), aluminum (Al3 +), copper (Cu2 +), zinc (Zn2 +) and manganese (Mn2 +), which are useful for plant growth and development.

ECa of the soil is influenced by a number of its properties. In order to be used as an indicator of soil health and therefore to inform the farmer of the activities to be undertaken, the relationship between ECa and other soil properties must be understood.

A field in which the EU is distributed according to a normal law is considered homogeneous. Deviations from the normal law are an indicator of deviations in their properties, [4,5], fig.2.

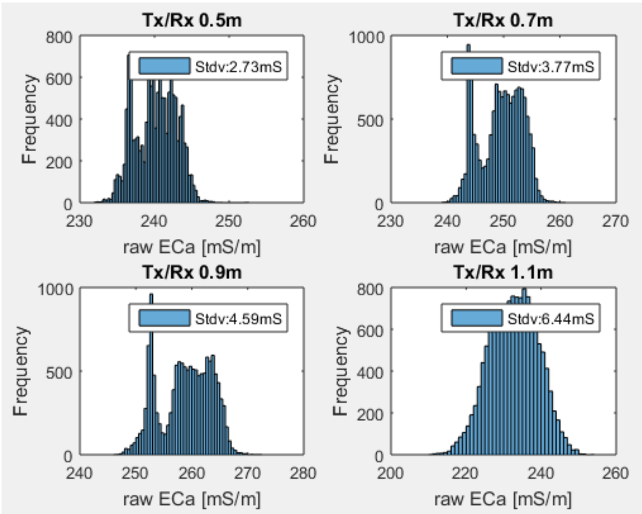

***Figure. 2.** Distribution of EU by depth of the studied horizons*

Soil salinization

The first indicator that must be taken into account when determining the condition of agricultural land is their salinity. About 35,000 ha of arable land (6% of agricultural land and 2.4% of irrigated land) are affected by salinization processes. The area of saline soils and the degree of development of the process are constantly increasing. The reasons for this are both global and regional in nature - unfavorable and lasting trends of climate change and hydrological conditions, irrigation with highly mineralized groundwater, natural or man-made deterioration of drainage conditions of intensively irrigated areas and increased fertilization with mineral fertilizers.

The vulnerability of soils to salinization and swamping is manifested in the lowest parts of the valley bottoms as a locally negative effect of the irrational artificial irrigation carried out in these areas.

Soil ECa is often used to determine salinity. Salinization is an indicator for determining the salt content of the soil. A basic rule for determining salinity is very high ECa values (> 1600 mS / m). The opposite is also true: very low ECa values (0-200 mS / m) indicate that the soils are not saline. Salinity is most affected by sodium cations, especially if they exceed 100 mg / kg of soil. Sodium can be extracted from the soil and thus reduce the level of ECa by adding gypsum, [18].

The research and the graphs in Fig. 3 show that from the point of view of salinization, the studied area is good for agricultural use.

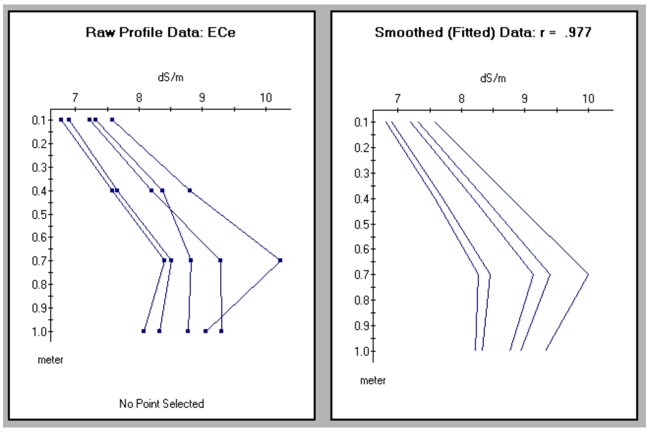

Figure 3. *Soil salinity values at the investigated soils*

The texture (content of sand, clay and fine particles), salinity, moisture and soil density are the properties that have the greatest impact on ECa.

Although the texture of the soil cannot be changed by its treatments, it is important to note how it interacts with ECa, [19,20,21].

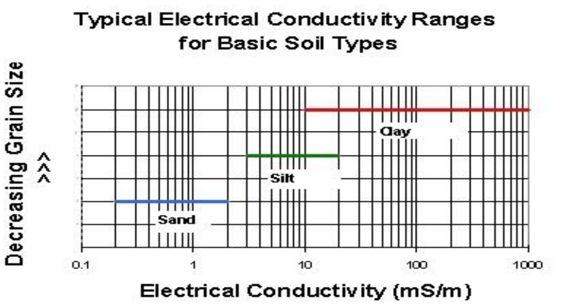

Figure. 4. Soil texture (sand, clay and silt content)

The sand has a low ECa (1-10mS / m), the fine particles (sludge) have average values (8-80 mS / m), and the clay - high ECa (20-800 mS / m).

This means that sandy soils have poor capacity to retain cations and easily lose nutrients compared to clayey and muddy soils.

Clay and muddy soils are much more likely to retain cations and the loss of nutrients will be much less than sandy soils.

Understanding this interaction, it can be considered that for each field with a specific texture at higher values of ECa lower values of mineral fertilization should be applied, as a small part of what is used will be lost by washing in more -lower soil layers.

The addition of organic matter to sandy soils can improve their ability to retain cations and thus improve ECa levels.

Another possibility for analysis of the measurement is that there are still parts of the fields in which the soil texture has not been measured. In such cases, ECa can present a good picture of the sand, clay and / or silt content using the above information.

Another indicator determining the physical properties of the soil is its density. The all-season use of heavy and energy-saturated machines, the annual plowing of the soils at the same depth, as well as other types of treatments at high humidity worsen their physical properties, Fig.5.

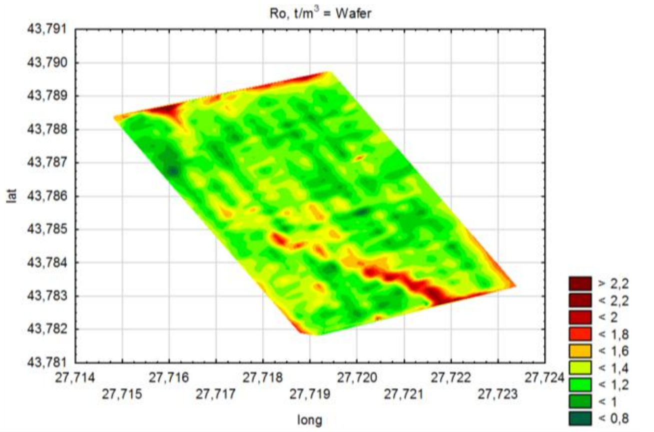

Figure 5. *Relationship between ECa and soil density*

The graphical dependence of fig. 6 shows a clear dependence that as ECa values decrease, soil density increases.

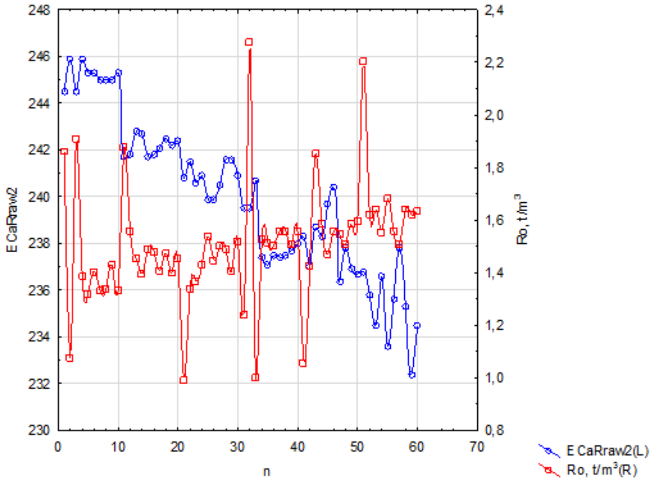

Fig.6. *Graphical relationship between ECa and soil density*

Soil moisture

The level of soil moisture plays a decisive role in the absorption of nutrients. Only water-soluble forms of these elements can be assimilated by plants. In case of shortage, the nutrients can be imported as fertilizers, but again the degree of their absorption is directly dependent on the presence of water in the root zone.

The indicator for the water content in the soils in the layer 0-100 cm is the percentage of the maximum field moisture content (PPV) at the beginning and the end of the vegetation period. The relative and absolute soil moisture can be determined.

Maps for spatial distribution of the water content in the layer 0 - 100 cm as a percentage of the maximum field moisture content (PPV) are widely used. It is more important to determine the soil moisture for each field and on this basis to calculate the norms for the introduction of nutrients into the soil.

It is important to note that when measuring ECa in the field, the higher the ECa, the more moisture the soil has. The explanation is in most cations in the soil solution. In general, water is a good conductor of electricity, and therefore, the more water there is in the soil, the better the soil conducts electrical impulses. In FIG. 7 shows the soil moisture for each point of the studied field. In the studied case the water content in the soil is in low limits.

For the conditions in the Republic of Bulgaria it is necessary to take urgent measures to improve the conditions for maintaining optimal soil moisture for a long period of time. It is best for the soil moisture to be in the optimal range throughout the growing season. This can be achieved by implementing results-based scientific solutions to tackle the effects of climate change.

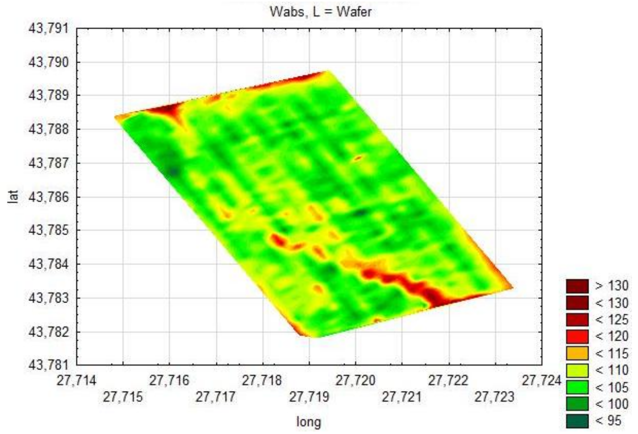

Fig.7. *Soil moisture determined by the ECa*

Relationship between ECa and soil chemical properties

In the cultivation of agricultural crops, in practice, a biological change of the soil in a given field occurs. This is due to the addition (introduction) of nutrients and organic matter into the soil and through their removal through plants or some degradation processes. The ratio of organic (active) carbon: nitrogen (C:N) shows the ratio of organic carbon to total nitrogen in the analyzed material. For agricultural purposes, such information can be obtained after soil analysis. The stock of soils with nutrients is determined by the content of total nitrogen, organic (active) carbon and total phosphorus, as well as the ratio between organic carbon and total nitrogen.

The C/N ratio is an indication of the conditions for the existence and development of soil biodiversity and for the stability of the soil structure. This attitude varies widely. In 2017 - 2018, the information about the presence of values of organic carbon in the soil 100-120 mg / kg of soil prevails. In some cases it reaches values up to 280 mg / kg soil. These values are not high.

The content and ratio of nutrients in the soil are directly related to soil fertility and plant nutrition.

Organic materials consist of carbohydrates, lignins, tannins, fats, oils, waxes, resins, proteins, minerals and other components.

With the exception of the mineral fraction, organic compounds are composed of different ratios of carbon and nitrogen. This is usually reduced to the C:N ratio.

Carbohydrates are composed of carbon (C), hydrogen (H_2) oxygen (O_2) decompose relatively easily to carbon dioxide (CO_2) and water (H_2O), plus a small amount of other by-products.

Protein-like materials are the main source of nitrogen compounds, as well as sources of carbon, hydrogen and oxygen, and are important for the development of the C:N ratio and the possible degree (rate) of decomposition of organic materials.

Aerobic heterotrophic bacteria are mainly responsible for the breakdown of large amounts of organic compounds generated on the earth's surface. These organisms usually have a C:N ratio of about 8: 1.

When organic residues are attacked by bacteria under suitable habitat conditions, some of the carbon and nitrogen are assimilated into the new and rapidly growing microbial population and a large amount of carbon dioxide is released into the atmosphere.

The number of bacteria is strongly controlled by the C:N ratio of the organic substrate.

As a rule, when organic residues have a C:N ratio of <30: 1 and are added to the soil, there is very little noticeable reduction in the amount of mineral nitrogen available for higher plant forms.

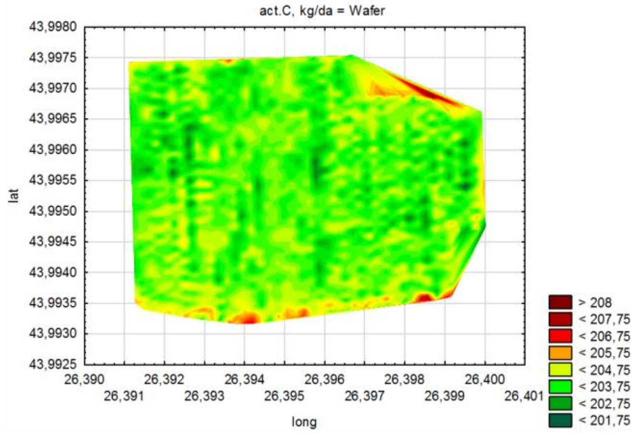

Figure .8. *Spectral map for the presence of organic carbon in the soil*

However, as the C:N ratio begins to increase to values greater than 30:1, there may be competition for mineral nitrogen forms.

The C:N ratio of plant material can well reflect the type and stage of plant growth. The younger plant usually contains more carbohydrates and less lignin, while the older plant of the same species will contain more lignin and less carbohydrates. The lignin tissue found in trees can have a C: N ratio of up to 1000:1.

The relative importance of the C: N ratio refers to two problems:

- the first is the rate of decomposition of organic matter to the low ratio C: N (formation of humus with an approximate ratio C: N = 10: 1);

- the second is the immediate presence of mineral nitrogen (NH + 4) to meet the demand for higher plant needs.

In cases where a C: N ratio of 30: 1 occurs (ie where there is a large amount of organic residue), the addition of mineral nitrogen to the organic residues is applied. This is a common practice to increase the rate of mineralization (rot) and to reduce the potential for nitrogen deficiency in higher plants.

Composting organic residues allows the decomposition of residues to take place without competition from higher plants for mineral nitrogen and also reduces the C: N ratio of the resulting mass to a C: N value of less than 20:1.

When this material is added to soil, it is unlikely to increase the potential for nitrogen competition between microorganisms and higher plants.

The largest CO_2 emissions from soils are due to tillage and amount to 20-40 t CO_2 / ha per year.

Nitrogen is a food source for microorganisms that break down carbon material. When the process is complete, soil microorganisms die and mineralize. In this way, the microbial nitrogen returns to the soil and becomes available to the plants.

The assessment of soil stock is made on a 5-point scale according to the content of organic carbon C, total nitrogen (N), phosphorus (P) and the ratio between organic carbon and total nitrogen in soils (C / N), which is regulated in Ordinance № 4 for soil monitoring (Table 1).

Table 1. *Scale for assessment of the content of nutrients in the soil. . Source: EEA, Report on the State of the Environment, MoEW, 2018*

Parameters	**орг. C mg/kg**	**общ N mg/kg**	**общ P mg/kg**	**C/ N**
Very low	< 50	<0,98	< 398	< 8
Low	50 -100	98-133	398 - 553	8 -10

Average	100 -150	133-195	553 - 924	10-12
High	150 -250	195-286	924 - 1599	>12
Very high	> 250	>286	>1599	> 30

By determining the electromagnetic conductivity of the soil and the developed methodology, it is possible to develop models for determining the amount of nutrients in the soil, fig. 9.

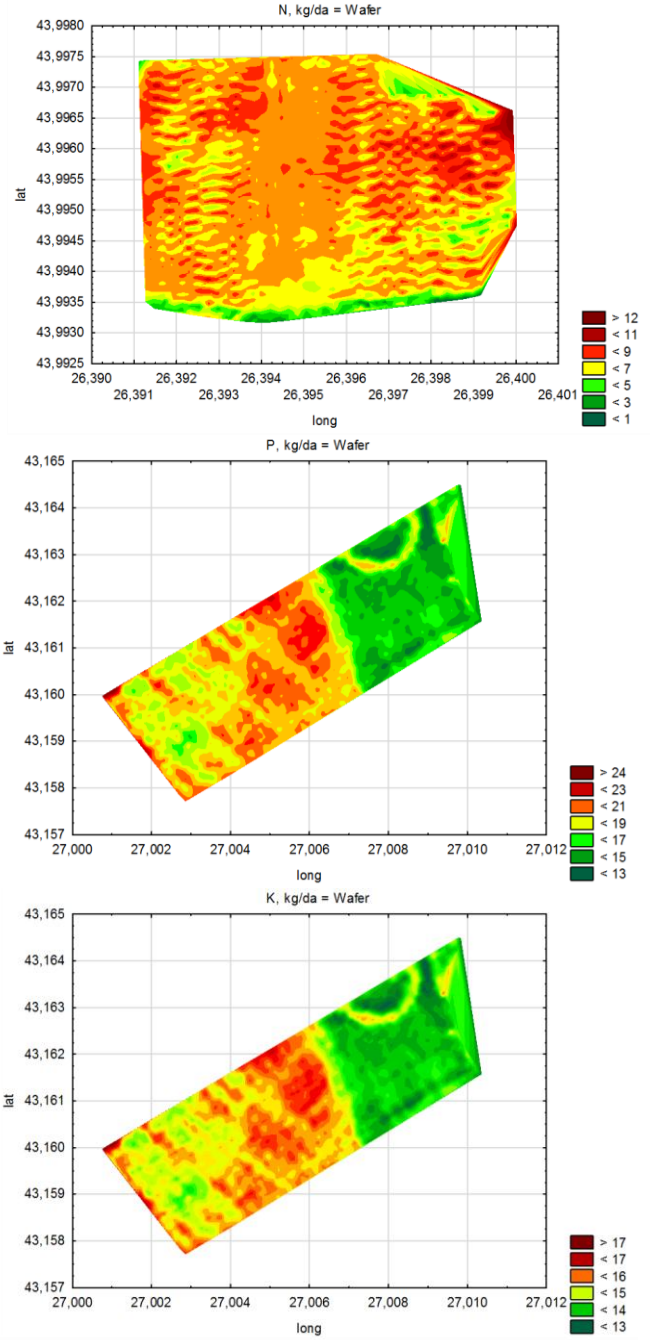

Figure 9. Spectral map for determining the content of nutrients in the soil.

In modern conditions, the development of fast and reliable tests for soil analysis requires working with a large database, processing a large amount of information and knowledge of the methods of mathematical statistics.

Conclusions

1. Soil electrical conductivity (ECa) is a measurement that correlates with soil properties that affect crop productivity, including soil texture, cation exchange capacity (CEC), soil hydraulic conductivity conditions, organic matter content. , salinity, characteristics of individual soil layers, etc.
2. The ECa of soils varies depending on the amount of moisture retained by the soil particles.
3. ECa strongly correlates with the size and structure of soil particles.
4. The apparent electrical conductivity of the soil is affected by a combination of physicochemical properties, including soluble salts, sand, clay and silt content, resp. soil water content, bulk density, organic matter and soil temperature.
5. Precision agriculture uses rapidly evolving electronic information technologies that change soil management in a site-specific way, with conditions changing spatially and temporally.
6. It is possible by measuring the electromagnetic conductivity of the soil to determine a number of indicators, the physical, chemical and biological properties of soils.

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