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Method of calculation of specific electrical conductivity of agro-biological soil environment by stationary contact method of operating electrodes of information and technical system of local operating monitoring

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Abstract. Modern agriculture involves the implementation of a particular technological operation, according to the appropriate map-task, which is developed pre-based on diverse information. Knowledge of a certain structure of soil cover variability, obtained using information and technical systems of local operational monitoring of agro-biological state of agricultural lands, allows us to adopt effective operational decisions for efficient management of agro-biological potential of agricultural lands.

Obviously, under such conditions, there is a need for fundamentally new approaches to agricultural production, which is to ensure the proper quality of technological operations. The quality of the implementation of technological operations is an integral indicator of the efficiency of production of agricultural products within the agro-biological field. The necessary quality of implementation of the basic technological processes in plant growing is provided by the integrated information and technical systems of operational monitoring of the agro-biological state of agricultural lands.

In connection with this, the task is to obtain reliable data on the agro-biological state of the soil environment by reducing the error in determining the magnitude of the conductive properties of the soil, providing individual stabilization of the working electrodes and the mechanism of lifting / lowering working electrodes, copying inequalities of the soil environment, reducing the intensity of the destruction of the soil structure , self-cleaning of the working contact of the electrode and ensuring the stability of the electrical contact of the electrode with the soil, by instrument design perfection. The task is achieved by using the information and technical system of operational monitoring of the soil environment of the structure to determine the conductive characteristics of the soil environment.

Keywords: information and technical system, local operational monitoring, soil, samples, variability, size, research.

FORMULATION OF THE PROBLEM

One of the main approaches in applying precision farming technologies is to optimize yields and ensure the ecological quality of agricultural products, taking into account agricultural management zones. In this aspect, the determination of soil electrical conductivity plays an important role in determining the magnitude of profit, based on the data of spatial variability and nutrient content in the soil. Knowledge of a certain structure of the variability of soil layer allows us to make effective decisions for managing the agro-biological potential of agricultural lands [1].

An overview of modern literary sources and scientific developments [1] shows that in recent years the process of integration of natural (organic or biological), biodynamic, extensive, intensive (industrial) and no-till agriculture with the latest technologies takes place, in particular with information and technical systems of local operational monitoring of the condition of agricultural land. At the same time, the latter direction is the most relevant and promising for the conditions of Ukraine.

Modern agricultural production involves the extensive use of automated systems for monitoring the condition of agricultural lands.

The implementation of modern agricultural technologies allows planning the costs of seed material, fertilizers, pesticides, and other technological materials, including fuel, to determine the overall strategy for managing the agro-biological potential of the field, and so on. However, at present, the implementation of these technologies lacks effective systems for collecting and registering (monitoring) localized information (agro-biological and phyto-sanitary) on the state of agricultural lands in precision farming technologies. Existing ways and means of implementing this process are imperfect [2-4].

In this sense, the development and use of a fundamentally new class of agricultural machines - information and technical systems of local operational monitoring of the agro-biological state of agricultural lands becomes relevant.

In this regard, the important task is to develop and substantiate the modern information and technical system of local operational monitoring of the agro-biological state of agricultural lands.

ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

The structure of the soil varies greatly in many agricultural fields. Physical properties of the soil, such as the soil structure, have a direct effect on water capacity, the capacity of cation exchange, yield, etc. Nutrients contained in soils are used by the plant and their content in the soil is reduced. The generally accepted characterization of nutrient content in soils is the content of nitrogen, the presence of which in soil largely determines the yield. Cartography of soil electrical conductivity is widely used as an effective means of mapping the soil structure and other soil properties [5]. A quick description of the variability of agricultural land is an important component for zonal management methods [6]. This variability is too important to ignore it and should be taken into account when taking samples (Fig. 1).

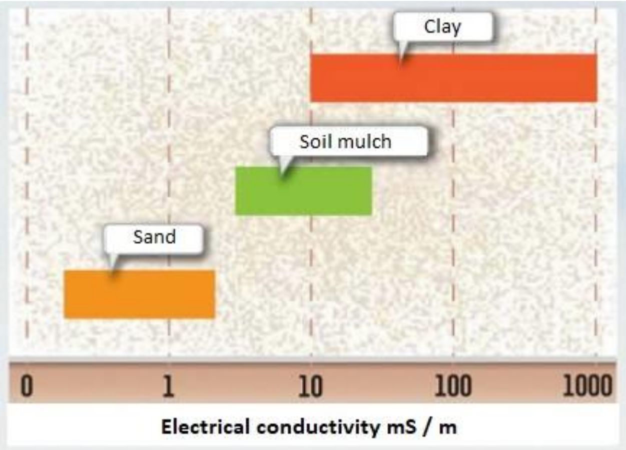

Fig. 1. The electrical conductivity of a soil

To map the soil with the EC Veris 3100 device, they use an off-road vehicle equipped with an onboard computer with parallel driving technology, a GPS receiver (Fig. 2) and a trailer unit with discs (located in disks electrodes). When carrying out measurements, the unit moves in the field with submerged discs to a depth of 2-5 cm, one pair of isolated electrodes enters the electric current into the ground; other electrodes measure the current, which varies depending on the resistance of the soil [4].

The Veris trailer unit moves along the field, one pair of isolated electrodes enters the electric current into the ground, and the other pair measures the voltage drop, which will be different - for example, the clay conducts current better than silt or sand. Measurements of electrical conductivity are combined with GPS data and are clearly displayed as a map. The Veris 3100 uses two electrical conductivity rays to map two depths of soil (0-30.5 cm and 0-91.5 cm) at the same time.

Veris 3100 forms two sets of maps - a map of the surface layer (30.5 cm) and a map of going deep to the root zone (91.5 cm). The top layer map is often used to select sampling points, and a deeper map to determine the fertilizer application rate (especially nitrogen) [5].

These devices are too costly and give a significant measurement error, which creates the conditions for further research of these systems.

The device for determining the conductive properties of the soil environment is used: before the execution of the technological operation, simultaneously with the implementation of the technological operation (sowing, application of mineral fertilizers, etc.); during the growing season and after harvesting. This opens new prospects for organic farming using such "smart" agricultural machines.

In Fig. 3 there a general view of the technical system of operational monitoring of the soil environment designed by Oleksander Brovarets (see above) is shown, Fig. 4 elicit a general view of the technical system of operational monitoring of the soil environment of the Oleksander Brovarets' design (side view).

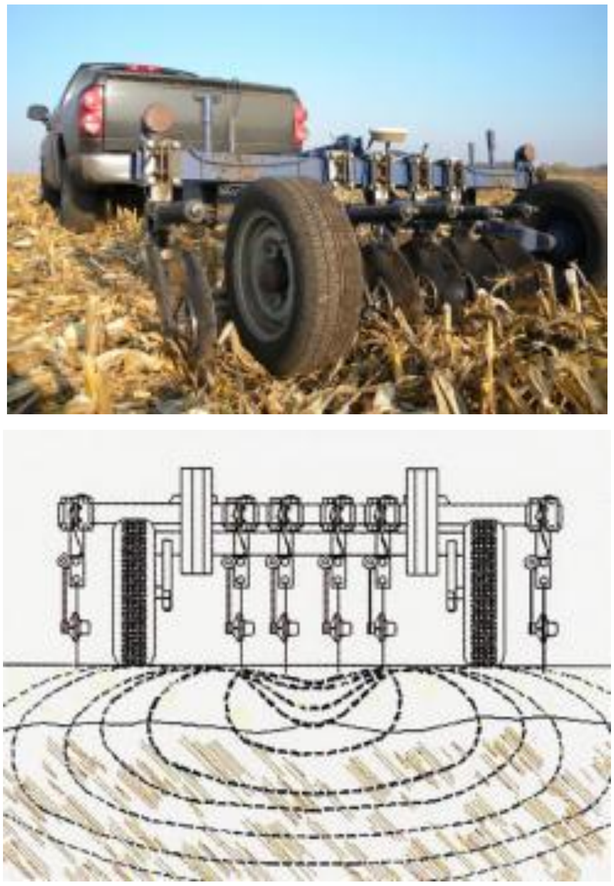

Fig. 2. EC Veris 3100 device

Such a technological solution will enable to provide optimum control of the sowing norm of technological material (seeds, fertilizers, etc.), taking into account the agro-biological state of the soil environment.

The technical system of operational monitoring of the soil environment designed by Aleksander Brovarets consists of the support wheels 1, П-shaped frame 2, fastening 3, longitudinal frame 4, transverse frame 5, hinges 6, levers 7, vertical springs 8, bracket 9, a rotary shaft 10, a hydraulic cylinder 11, a mount bracket 12, gage wheels 13, working electrodes 14, a ballast 15, a tow 16 and a stand 17.

When using such a device, there is a significant error in determining which occurs according to the fact that during the work process the stability of the contact of the disk electrode with the ground is disturbed due to the transverse deviations of the working disk electrodes relative to the straight line of motion as well as due to the construction of the device and the lack of copying the surface irregularities of fields with disk electrodes. Along with this, the contact area of the disk electrode with the soil changes, because in the case of transverse oscillations, flat disks electrodes with one side may not contact the soil at all.

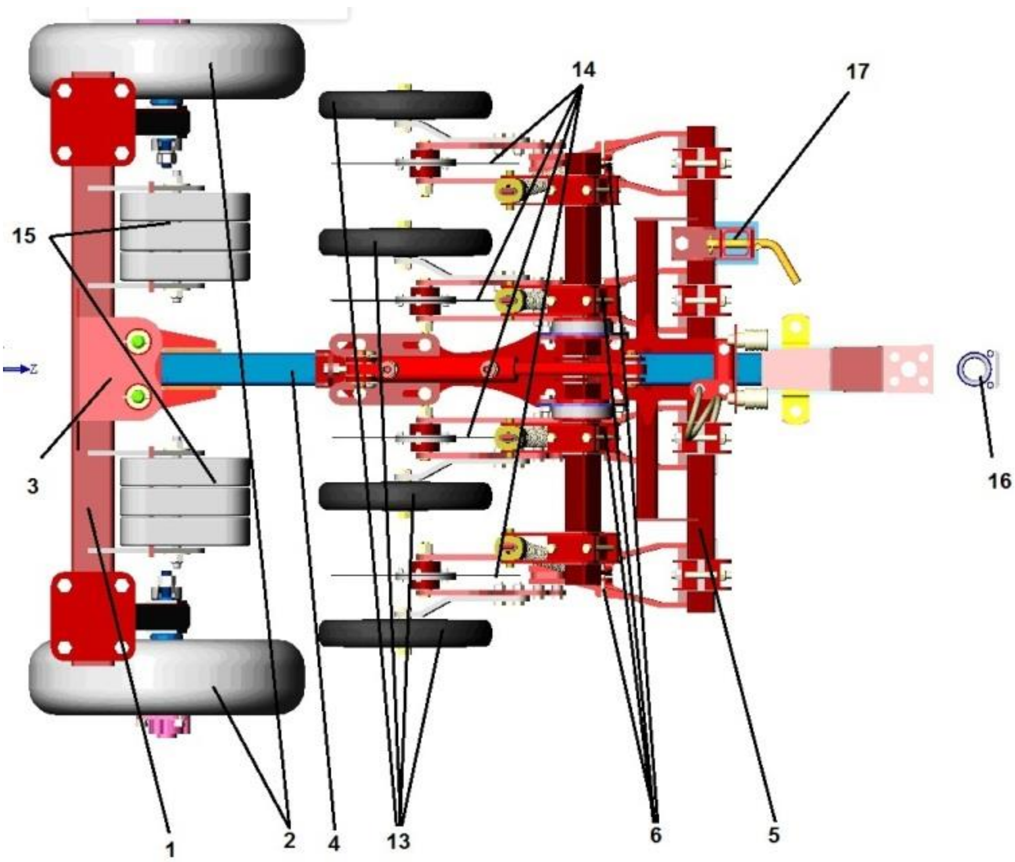

Fig. 3. General view of the information and technical system of local operational monitoring of the soil environment state

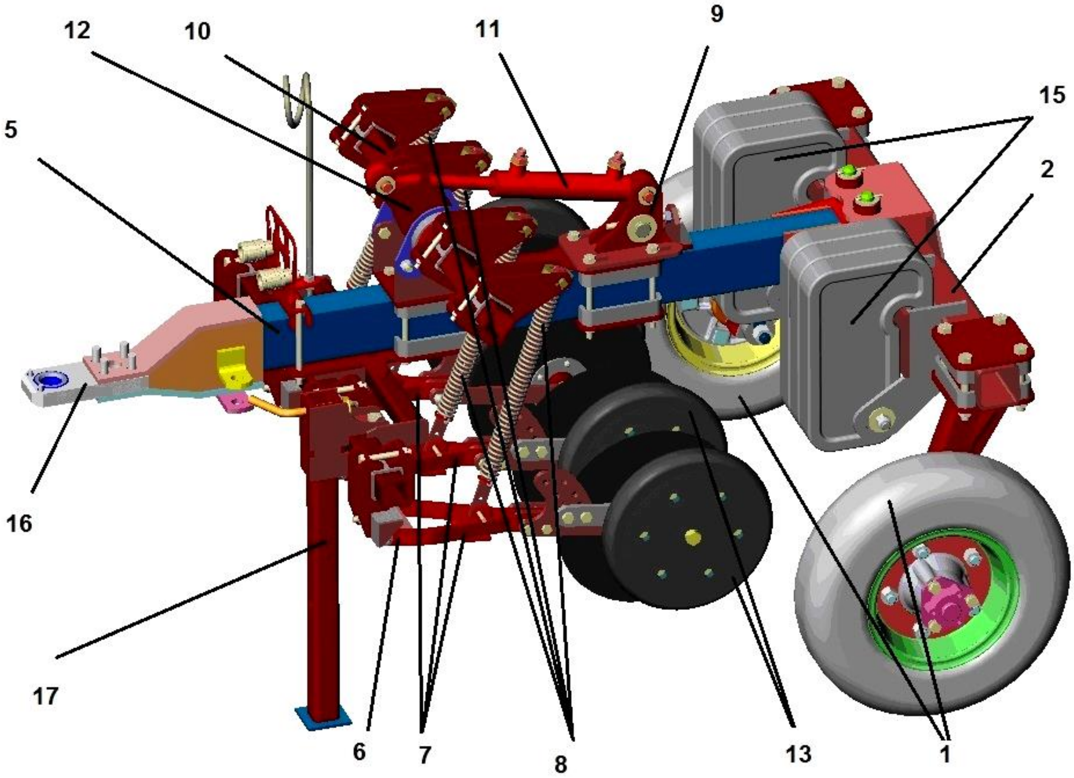

Fig. 4. General view of the information and technical system of local operational monitoring of the agro-biological state of the soil environment

The purpose of this study is to develop a method for calculating the specific electrical conductivity of agro-biological ground environment by the stationary contact method of working electrodes of the information and technical system of local operational monitoring.

Presentation of the main content of the study. ***Measurement of conductive properties of the soil environment***. Soil electrical conductivity is the property of the material to transmit (conduct) electric current, measured in Siemens per meter (S / m) or milliSiemens per meter (mS / m).

The scope of the device usage for determining the conductive properties of the soil environment of the Oleksander Brovarets's design. The information and technical system of operational monitoring of the soil environment of Oleksander Brovarets - a device for determining the electrical conductive properties of the soil environment of the Oleksander Brovarets's design can work with manual devices, be placed on high-permeability vehicles, on agricultural and energy vehicles, which carry out a technological operation that allows to receive operational data on the agro-biological state of the soil environment and to take operative decision on controlling the rate of introduction of technological material (seeds, mineral fertilizers, etc.).

An important parameter in measuring the conductive characteristics of the soil environment is to provide a stable contact area of the working electrodes with the soil. The existing designs do not fully fulfill the specified conditions, which negatively affects the reliability of the information received. In connection with this, there was a need to develop a design that would ensure the stability of the working electrodes with the soil during the measurement of the conductive properties of the soil environment.

To illustrate the drawbacks of the existing design and the advantages of the developed design, their diagrams are shown in Fig. 5.1, Fig. 5.2, Fig. 6.

It is worth to say that the designs of the available and developed systems have a number of common elements (Fig. 5.1, Fig. 5.2, Fig. 6), in particular the common elements are: 1 support wheel, 2 frame, 3 working electrode. Further, the existing system consists of 4 - stand, which is rigidly connected to the frame, so when moving on agricultural lands, such a system can form furrows of width h, due to the appearance of the banking angles, the deferent and the yaw caused by non-rectilinear motion of the aggregates, their deviation or rotation. In its turn, this contributes to the measurement error of the conductive parameters of the soil environment, since one side of the disk does not contact the soil at all (Fig. 5.2, a).

In the developed design, this problem is eliminated due to the compensation of such angles partly due to the suspension, and in part - the upper and lower suspension hinges of the developed design, which allow us to compensate for the transverse deflection α within 15-20 degrees, while ensuring a stable contact of the electrodes with the soil. With the use of gage wheels 6 (Figs 4.1, 4.2, Fig. 5), the existing structure clearly provides the depth *H* of the motion of the working electrodes in the soil. In the existing structure (Fig. 4.1, Fig. 4.2, Fig. 5), it changes due to the corners of the deferent, due to oscillations and lateral displacement of the structure of the system during the movement of the surface irregularities of the field.

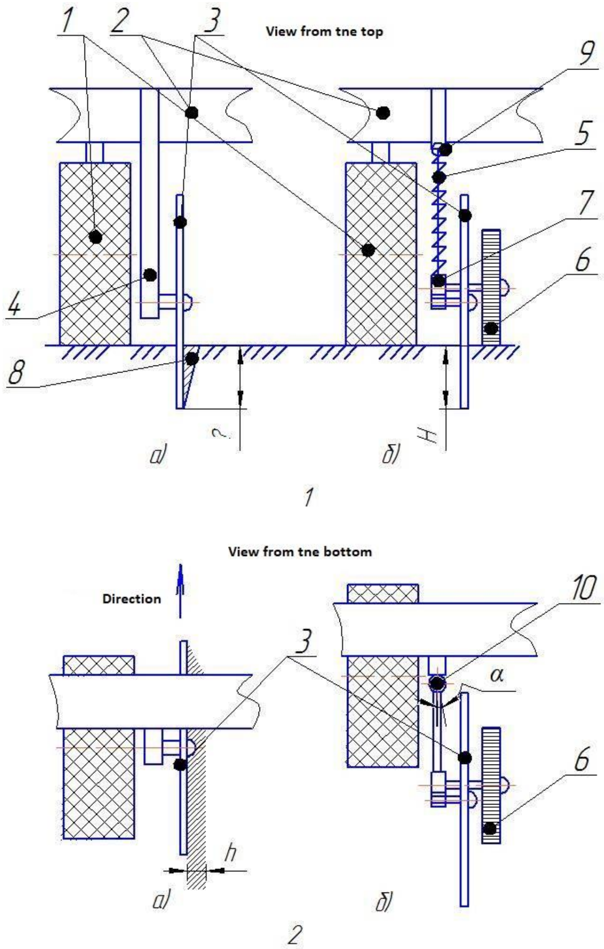

Fig. 5. Comparative scheme of the device for determining the conductivity characteristics of the soil environment (front view, top view):
a) available construction; b) the developed design;
1 - support wheel; 2 - frame; 3 - working electrode; 4 - stand; 5 - vertical suspension stand; 6 - gage wheel; 7 – the adjustment mechanism of the depth of the wheel; 8 - furrow formed by a working electrode; 9 - upper hinge; 10 - lower hinge

The general principal differences of the information and technical system of local operational monitoring of the agro-biological state of the soil environment - a device for determining the conductive properties of the soil environment are:

1. Presence of a gage wheel, which determines the depth of the working electrode in the soil *H*.

2. Suspension of the bearing wheel and working electrodes.

3. Three-spoke thin-walled metal disk with a rim to provide a stable area of contact of electrodes with soil.

4. Articulation of the lever suspension of working electrodes with soil to compensate for the banking angles, the deferent and the yaw, caused by the movement of the

machine-tractor unit by the information and technical system of operational monitoring of the agro-biological state of the soil environment designed by Oleksander Brovarets and ensuring the stable contact of the working electrodes with the soil.

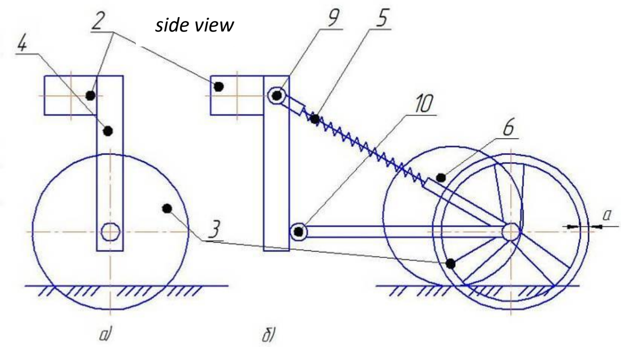

Fig. 6. Comparative scheme of the device for determining the conductivity characteristics of the soil environment (side view):

a) available construction; b) the developed design;

2 - frame; 3 - working electrode; 4 - stand; 6 - support wheel; 5 - vertical suspension stand; 9 - upper hinge; 10 - lower hinge

The technical result, which is achieved using the information and technical system of local operational monitoring of the agro-biological state of the soil, is as follows.

1. Ensuring a stable contact of the electrodes with the soil: due to the compensation of the banking angles, the deferent and the yaw, caused by the movement of the technical system.

2. Determination of the depth of entry of the working electrode into the ground using a gage wheel.

3. Decrease in area growth per unit depth / entry into the soil of the working electrode due to the construction of a three-spoke thin-walled metal disk with a rim in the developed design.

4. The absence of the formation of a furrows by working electrodes due to the compensation of the angle of rotation by the upper and lower hinges of the suspension of the angle α.

Method of calculation of specific electrical conductivity of soil (ρ) by stationary contact method.

The device for determining the conductive properties of the soil environment *makes it possible to quickly identify the zones of variability of the agro-biological state of the soil environment*, provide an "individual" approach to each elementary plot of the field using the data of the conductive properties of the soil environment and identify them with further laboratory analysis.

Such a technological solution will enable to provide optimum control of the norm of sowing of technological material (seeds, fertilizers, etc.), taking into account the agro-biological state of the soil environment.

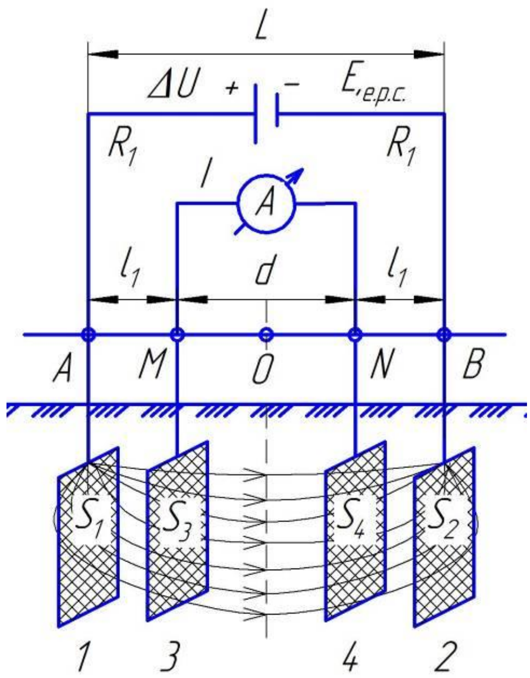

Fig. 7. The calculation scheme of measurement of the specific conductivity of the soil environment of agricultural lands using the information and technology system of local operational monitoring of their agro-biological state of agricultural lands of the soil environment

Let us deduce the formula for determining the specific electrical conductivity. We design the equivalent calculation scheme of the information and technical system of local operational monitoring of the agro-biological state of agricultural lands' soil environment. (Fig. 1).

In the scheme, we will accept, that $S_4 = S_3$ $S_2 = S_1$. Maybe it will be true, that $S_3 = S_4$, $S_1 = S_2$.

Method of calculation of specific electrical conductivity of soil (ρ) by stationary contact method.

Let us mark $S_4 = S_3$ $S_2 = S_1$.

Ohm's Law for a Complete Circuit (Locked Up):

$$I = \frac{E_{e.p.c.}}{R + r}, \quad (1)$$

where $E_{e.p.c.}$ is the electromotive force of the battery, B; R - total resistance of the circle, Ohm; r - internal resistance of the battery, Ohm.

$$R = 2 \cdot R_1 + \frac{\rho \cdot 2 \cdot l_1}{S_1} + \rho \cdot \frac{d}{S_з}, \quad (2)$$

where R_1 is a resistance of wires and extreme probes, Ohm; $[\rho] = Ohm \cdot m$ is a specific resistance of soil;

S_1 is a cross-sectional area of the working electrode immersed in the soil (external working electrodes (probes) 1 and 2);

S_3 s a cross-sectional area of the working electrode immersed in the soil (internal working electrodes (probes) 3 and 4).

Mark according to the scheme $S_3 = S_4$, $S_1 = S_2$.

Let us assume that $S_1 = S_2 = S_3 = S_4 = S$. Then the formula for R will look like:

$$R = 2 \cdot R_1 + \frac{\rho}{S} \cdot (2 \cdot l_1 + d). \tag{3}$$

Consequently, the formula for calculating the current takes the form of:

$$I = \frac{E_{e.p.c}}{2 \cdot R_1 + \frac{\rho}{S} \cdot (2 \cdot l_1 + d) + r}. \tag{4}$$

Voltage U, B on site 3 - 4 is defined as follows:

$$U = I \cdot \frac{\rho}{S} \cdot d;\ [U] = Volt \tag{5}$$

The current density at the working electrodes of the information and technical system of local operational monitoring of the agro-biological state of agricultural lands (per unit area of the cross section of the plot (3 - 4)) has the form:

$$j = \frac{I_{circuit}}{S};\ [j] = \frac{A}{м^2} \tag{6}$$

The current density is defined as follows:

$$j = \sigma \cdot E, \tag{7}$$

where E is the intensity of the electric field at the site of the working electrodes 3 - 4,

$$[E] = \frac{B}{m}, \tag{8}$$

$$\sigma = \frac{j}{E};$$

$$[\rho] = \frac{\left(\frac{A}{m^2}\right)}{\frac{B}{м}} = \frac{A}{B \cdot m} = \frac{1}{\left(\frac{B}{A}\right) \cdot m} = \frac{1}{Ohm \cdot m} = \frac{\frac{1}{Ohm}}{m} = \frac{S}{m} = \frac{Siemens}{m}$$

Therefore, $[\sigma] = \frac{S}{m}$.

Considering the field at the sites 3 - 4 homogeneous electric field, we can determine:

$$E = \frac{U}{d}. \tag{9}$$

We substitute (9) and (4), (6) for formula (8), then finally we have:

$$\frac{E_{e.p.c}}{\left(2 \cdot R_1 + \frac{\rho}{S} \cdot (2 \cdot l_1 + d) + r\right) \cdot S} = \sigma \cdot \frac{U}{d}.$$

$$\sigma = \frac{E_{e.p.c} \cdot d}{\left(2 \cdot R_1 + \frac{\rho}{S} \cdot (2 \cdot l_1 + d) + r\right) \cdot S \cdot U} = \frac{E_{e.p.c} \cdot d}{\left(2 \cdot R_1 + \frac{\rho}{S} \cdot (2 \cdot l_1 + d) + r\right) \cdot S \cdot \left(\frac{\rho}{S}\right) \cdot I \cdot d} = \frac{E_{e.p.c}}{\left(2 \cdot R_1 + \frac{\rho}{S} \cdot (2 \cdot l_1 + d) + r\right) \cdot S \cdot I \cdot \left(\frac{\rho}{S}\right)} = \frac{E_{e.p.c}}{\left(2 \cdot R_1 + \frac{\rho}{S} \cdot (2 \cdot l_1 + d) + r\right) \cdot I \cdot \rho}. \tag{10}$$

Finally,

$$\sigma = \frac{E_{e.p.c}}{\left(2 \cdot R_1 + \frac{\rho}{S} \cdot (2 \cdot l_1 + d) + r\right) \cdot I \cdot \rho}. \tag{11}$$

$$[\sigma] = \frac{S}{m}.$$

It is true:

$$[\delta] = \frac{Volt}{(Ohm) \cdot A \cdot (Ohm \cdot m)} = \frac{A}{A \cdot (Ohm \cdot m)} = \frac{\frac{1}{Ohm}}{m} = \frac{S}{m}.$$

So, the result: I - we measure at Ampere, then $[\sigma]_{soil}$, $\frac{S}{m}$:

$$\sigma_{soil} = \frac{E_{e.p.c}}{\left(2 \cdot R_1 + \frac{\rho}{S} \cdot (2 \cdot l_1 + d) + r\right) \cdot I \cdot \rho}. \tag{12}$$

The units of measurement of the proposed parameters are as follows: $[E_{e.p.c}] = B$, $[R_1] = [r] = Ohm$; $[\rho] = Ohm \cdot m$; $[l_1] = [d] = m$; $[I] = Ampere$; $[E_{e.p.c}]$, [r] - rating data of the power source (batteries); S, l_1, d - geometrical dimensions of the installation; ρ - specific resistance of the soil (determined in advance).

Essentially, $\sigma = \frac{1}{\rho}$. That is, the resistivity is the reversal of electrical conductivity. Therefore, we have:

$$\frac{1}{\rho} = \frac{E_{e.p.c}}{\left(2 \cdot R_1 + \frac{\rho}{S} \cdot (2 \cdot l_1 + d) + r\right) \cdot I \cdot \rho}. \tag{13}$$

From here we have

$$1 = \frac{E_{e.p.c}}{\left(2 \cdot R_1 + \frac{\rho}{S} \cdot (2 \cdot l_1 + d) + r\right) \cdot I}. \tag{14}$$

Then, from (14) we have:

$$2 \cdot R_1 + \frac{1}{\sigma \cdot S} \cdot (2 \cdot l_1 + d) + r = \frac{E_{e.p.c}}{I}. \quad (15)$$

$$\frac{1}{\sigma \cdot S} \cdot (2 \cdot l_1 + d) = \frac{E_{e.p.c}}{I} - 2 \cdot R_1 - r. \quad (16)$$

$$\frac{1}{\delta \cdot S} = \frac{\left(\frac{E_{e.p.c}}{I} - 2 \cdot R_1 - r\right)}{(2 \cdot l_1 + d)}. \quad (17)$$

$$\sigma \cdot S = \frac{(2 \cdot l_1 + d)}{\left(\frac{E_{e.p.c}}{I} - 2 \cdot R_1 - r\right)}. \quad (18)$$

The final formula for calculating the specific electrical conductivity of the soil using the information and technical system of local operational monitoring of the agro-biological state of agricultural land is:

$$\sigma = \frac{(2 \cdot l_1 + d)}{S \cdot \left(\frac{E_{e.p.c}}{I} - 2 \cdot R_1 - r\right)}. \quad (19)$$

Dimension:

$$[\sigma] = \frac{m}{Ohm} = \frac{S}{m}. \quad (20)$$

CONCLUSION

The proposed method for calculating the specific electrical conductivity of the agro-biological soil environment by the stationary contact method of the working electrodes of the information and technical system of local operational monitoring will allow obtaining reliable data on the soil environment by reducing the error in determining the magnitude of the electrical conductive properties of the soil, providing individual stabilization of the working electrodes and the mechanism of lifting / lowering the working electrodes , copying of irregularities of soil environment, reduction of the intensity of destruction of the soil structure, self-cleaning of the working contact of the electrode, and the stability of the electrical contact of the electrode with the soil, by improving the design of the device, using the proposed methodology.

The result of using the device to determine the electrical conductive properties of the soil environment is to obtain a 20-30% increase in profits by optimizing the sowing rate of the technological material, taking into account the agro-biological state of agricultural lands.

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