Revista Publicando, 4 No 13. (2). 2017, Pr214-Pr226. ISSN 1390-9304

Experimental Application Of Basic Hydrophysical Characteristic Of Soils In Order To Optimize Their Qualitative Characteristics And Agricultural Soil Quality Evaluation Criteria

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ABSTRACT

The most informative characteristic of soils, which allows to differentiate them according to the availability of moisture to plants from the energy point of view, i.e. it is the basic objective hydrophysical characteristic (OHPC). OHPC equation expressing the relationship between the pressure equivalent to moisture potential and the volumetric moisture content for soils with different specific surfaces and porosity values can be used to solve many problems of soil quality research and their parameters regulation for optimal use, primarily in agricultural purposes. Since the hydrophysical parameters of a soil vary very much spatially, then for the purpose of objective obtaining of reliable indicators, one should rely not only on the registration and the analysis of a natural territorial complex and the ecological features of a particular region, but also on the results of quantitative-qualitative field stationary studies.

Keywords: Hydrophysics of soils, basic hydrophysical characteristics, terms of soil treatment, cadastral estimation, soil mixture, qualitative assessment of soils.

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1. INTRODUCTION

In a short term, we should expect a more profound impact of the anthropogenic factor on the natural-territorial complexes (NTC). In this regard, there is a growing need to study the causes and the factors affecting stability (flexibility, resistance) both in the whole NTC and the soil cover to all types of anthropogenic loads, and primarily agricultural ones.

The patterns of the landscape-forming process evolution, the internal relations of NTC, taking into account specific anthropogenic conditions, were not studied sufficiently. Simultaneously, one of the landscape-forming systems "soil-plant-air" - the most important component of the natural and anthropogenically altered landscape, is the main means of production in agriculture and forestry. Therefore, the subsystems "soil" and "air" must meet the requirements that would meet the necessary conditions for the functioning and the sustainable development of the subsystem "plant".

2. METHODS

The thermodynamic method is based on the measuring of moisture binding energy in soil and is explained by the fact that due to the intracellular content of dissolved substances and transpiration plants create an osmotic pressure that determines the intensity of moisture flow from a soil to a plant, while the soil seeks to retain this moisture by is capillary, sorption forces, etc. In this case, if the forces that retain moisture in a soil (the "suction force", which can be expressed through pressure) lie within the range of osmotic pressure values that a plant can create, then the latter exists as an organism.

The limits of osmotic pressure variation among cultivated plants depend on their type and lie in a rather narrow range up to 0.1 atm. for the most hygrophilous, and up to 30 atm. for the most drought-resistant ones. Given that the "suction force" of a soil reaches more than 3000 atm., it can be argued that the potential of soil moisture - the binding energy of moisture in a soil, referred to a unit of moisture mass, is a limiting factor in a soil-plant-air system, comparable by its influence with such a factor as temperature. Besides, it should be noted that the optimal - "comfortable" - conditions for the development of cultivated plants lie in an even narrower range of moisture potential values, from 0.1 to 1 atm. For this type of soil and for a plant of a particular culture, "comfortable" conditions are realized by maintaining the total moisture within the limits corresponding to the optimum values of moisture potential. This is related with the soil to transport moisture to the roots of plants in quantities sufficient to cover its costs for transpiration. Transport ability of soil is determined by its filtration characteristics in terms of moisture transfer. First of all, it is determined by filtration ratio, which strongly depends on the degree of soil compaction. This value significantly affects one of the main mechanisms of soil degradation - water erosion (Sirotkin V., Vasyukov S. Usmanov, B.. 2016). Regardless of a method used to evaluate the soil erosion process: the kinematic according to the flow spreading velocity, dynamic one according to the resistance to erosion or the energetic one, according to the potential of the erosion resistance, it is necessary to take into account the part of a water flow that seeps into a soil, which requires the knowledge of the filtration coefficient for this soil (Sirotkin V.V., Vasyukov S.V. 2014).

3. RESULTS AND DISCUSSION

1. The use of the basic hydrophysical characteristic for a comparative (cadastral) assessment of different soils

At present, the cadastral estimation of soils is carried out in many parameters, the only one which reflects the physical properties is the mechanical composition, i.e. only the distribution of primary particles by size is taken into account. This parameter allows us to classify soils in a wide range from gravel to heavy clay, but does not allow us to judge their water and physical properties, the most important of which is the amount of moisture available to plants and the nature of its variation, depending on the moisture content. The conclusion on the value of this or that soil by this property can be given by NTC.

The equivalent pressure corresponding to the boundary value of the moisture potential still accessible for a plant is determined by an equation similar to A.D. Voronin's equation (Voronin A.D. 1990) after potentiation:

$$p = 10^{3.17 + 3W\frac{\rho_{воды}}{\rho_{сух}}}, \qquad (1)$$

where W is the volumetric moisture content; $\rho_{воды}$ – the density of water; $\rho_{сух}$ – the bulk mass of a dry sample.

If we solve jointly the equation for NTC

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$$P = P' + P'' = \frac{\Omega_0 \sigma_{l\,g} (1 - P_0)}{P_0^{2,5}} \frac{(P_0 - W_{Vi})^{2,5}}{1 - (P_0 - W_{Vi})} + \frac{A\Omega_0^3}{W_{Vi}}$$ (2) and the equation (1)

(3), (where W is the volumetric moisture; $\rho_{воды}$ is water density; $\rho_{сух}$ is the bulk mass of a dry sample), then a point of curve intersection can be obtained expressing some boundary value of the volumetric moisture ***a*** below which moisture is no longer available to plants. The area bounded by NTC is within the limits of moisture values from the full filling of pores W = P_0 where P_0 is the porosity and up to W = a it reflects the energy that must be expended in order to take all the moisture available to the plants. This value by physical essence is the free Gibbs energy per unit of soil volume within these limits. It can serve as soil estimation criterion and is expressed as follows:

$$F = p\frac{V_{воды}}{V_{обр}}, \qquad (3)$$

where is the free energy; - equivalent pressure; - volumetric moisture.

The required area can be found by the following integration

$$\int_a^p F dw = \frac{1}{2}\frac{\sigma_{\lg}}{P^2}\frac{A\Omega_0^3}{a^2}\left(P^2 - a^2\right) + $$
$$+ \frac{2\sigma_{\lg}\ \Omega_0 (P-1)}{P^{2.5}}\left(\frac{(P-a)^{2.5}}{5} + \frac{(P-a)^{1.5}}{3} + (P-a)^{0.5} - arcth(P-a)^{0.5}\right)$$

(4)

where σ_{lg} is the surface tension coefficient at the liquid-gas interface; Ω_0 is the volumetric specific surface.

The analysis of equation (4) shows that this dependence has its maximum for the soil with some parameters. Fig. 1 shows the dependence for a sample with the porosity P_0 = 0.5. This value is so small that a plant planted on it experiences an acute shortage of moisture even with complete moisture saturation. This is the value as the criterion for the estimation of soils from the point of view of the moisture supply of plants.

2. NTC use to calculate the amount of components introduced into soil in order to improve its water-physical properties

Also, the course of the moisture potential dependence curve on humidity can be used to assess the effect of additives to an original soil that change its specific surface. For example, sand is added to the soil of a heavy clay composition or a physical clay to the soil of coarse texture. Such soils are called mixed ones.

For example, let's consider the effect of rotten-stone introduction in a soil with a low specific surface (Sirotkin V.V. 2002, Sirotkin V.V., 2001, Skrebkov G.P. 1998).

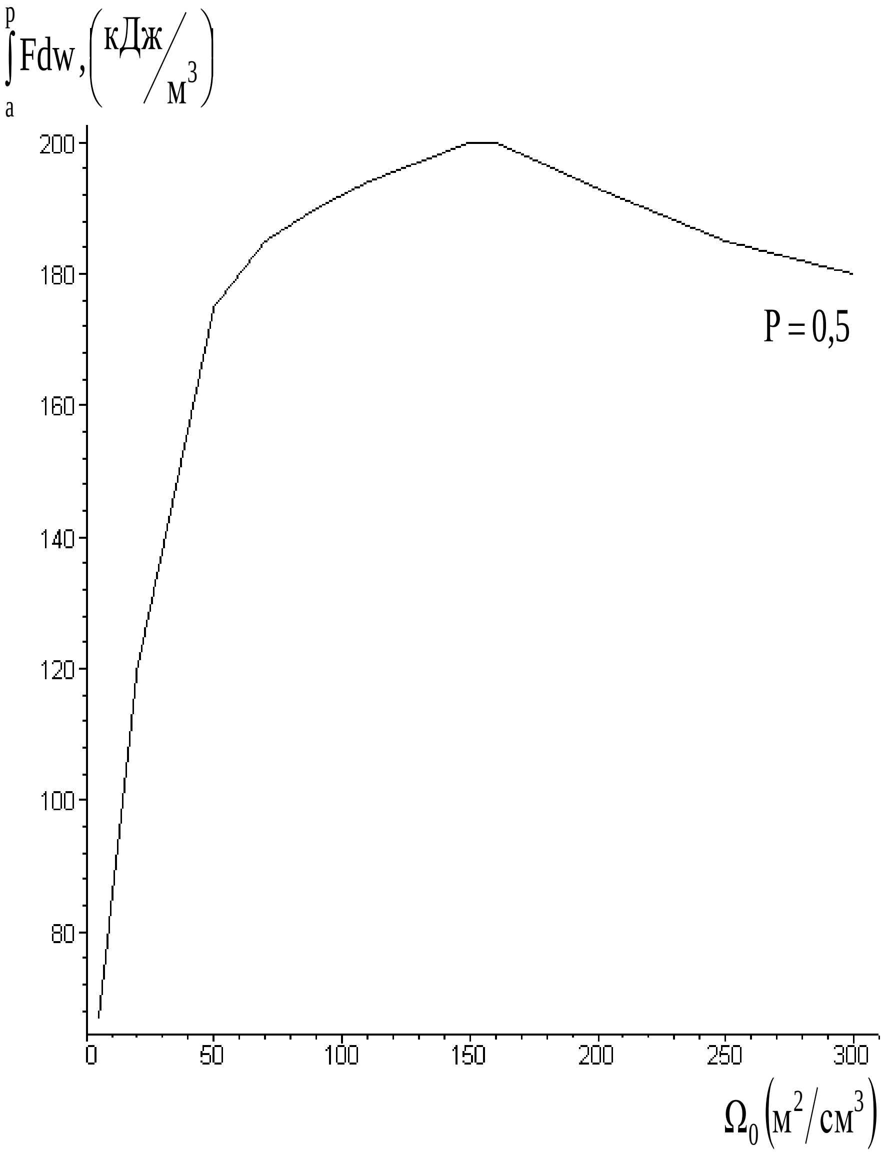

Fig.1. The dependence between the specific free energy of Gibbs in the range of moisture available to plants for the soils with different specific surface and porosity makes 0.5

In studies of rotten-stone influence on soil properties they consider mainly the issues associated with the changes of soil physical and chemical characteristics, such as the absorption capacity, the degree of saturation with bases, hydrolytic and exchange acidity, etc. In the present work, an attempt is made to evaluate the influence of the introduced rotten-stone on the hydrophysical characteristics of soil quantitatively.

On the basis of the experimental data, the physical characteristics of Shumsky deposit rotten stone in Chuvash Republic are the following ones: bulk density ρ_v=(1,974÷1,158)10^3 kg/m^3; solid phase density ρ_s=(2,61÷2.81)10^3 kg/m^3; the porosity of bulk samples P=(0.58÷0.64); specific surface area Ω=(800÷1100) m^2/m^3. ρ_v and P values are varied within these limits, depending on the fraction size and the degree of compaction. The values ρ_s and Ω depend on the variability of these values from a sample to a sample.

Obviously, its specific surface area has the greatest influence on the change of soil hydrophysical characteristics during rotten stone introduction since it considerably exceeds the soil value.

During rotten stone introduction into soil, the specific surface area of the mixture grows since $\Omega_2 >> \Omega_1$.

The conditions for the growth of plants from the point of view of their moisture supply are determined by the basic hydrophysical characteristic (NTC), expressed by the relationship between a specific energy of moisture retention in soil and its moisture content. This dependence includes the value of the specific surface and is determined by the following expression:

$$\psi = \psi'' + \psi' = \frac{\Omega \cdot \sigma_{lg}\left(1-P\right)}{\rho_w \cdot P^{2.5}} \cdot \frac{\left(P-W_{vi}\right)^{2.5}}{1-\left(P-W_{vi}\right)} + \frac{A\Omega^3}{\rho_w \cdot W_{vi}^3}, \qquad (5)$$

where ψ'' - the capillary component of the potential; ψ' - the adsorption component of the potential; σ_{lg}- the coefficient of surface tension at the liquid-gas interface; ρ_w- water density; W_{vi}- the current value of volumetric humidity; A=8,35 10^{-20}J – Deryagin’s constant.

In order to estimate the influence of the rotten-stone on NTC, let's construct it for chernozem with the following parameters: ρ_v=1,1 g/cm^3; Ω=80 m^2/g; P=0,55 (fig.2) and an original soil with the following parameters ρ_v=1,14 g/cm^3; Ω=30 m^2/g; P=0,55.

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This chart was covered by NTC for the mixture obtained as the result of rotten stone introduction in the initial soil at the rate of 10 tons/ha with the depth of tillage of 20 cm. The mixture parameters: ρ_v=1,14 g/cm^3; Ω=33,6 m^2/g; P=0,55.

Figure 2 shows how the curve for the mixture is shifted from the curve for the original soil toward the curve for chernozem, which indicates the improvement of hydrophysical properties. Obviously, the greatest positive effect of rotten stone introduction can be obtained for the soils with a low specific surface area.

3. Determination of soil cultivation time using NTC

The equation of the relationship between the moisture potential and humidity is known (Voronin A.D. 1990), which makes it possible to determine the value of potential and humidity corresponding to the state of soil "ripeness" for different soils: where p is potential.

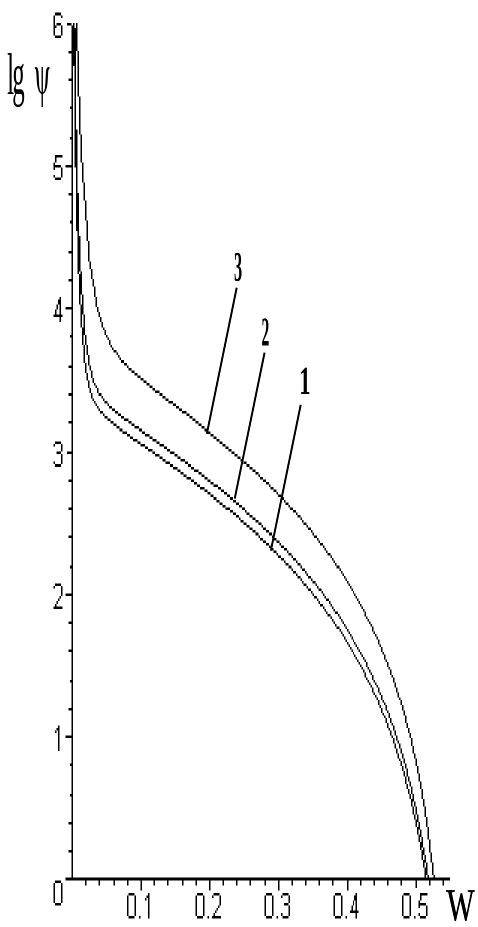

Fig.2. NTC graphs for chernozem (3), mixture (2) and original soil (1)

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$$lgp=2.18+3w, \qquad (9)$$

The superposition of a straight line according to the equation lgp=2.18+3w on the graphical dependences of NTC for soils with different values of a specific surface within one field makes it possible to determine the interval of volumetric moisture values corresponding to the "mature" state of the soil in a given field, i.e. to the state which corresponds to minimum energy costs during soil cultivation.

Figure 3 shows the computer curves of NTC developed according to the equation (4) for a field with the predominance of sod-podzolic soil (curve 1 for $\Omega_0=3*10^7$ m^2/m^3, curve 2 for $\Omega_0=3{,}7*10^7$ m^2/m^3) and the curves for a field with the predominance of chernozem (curve 3 for $\Omega_0=8*10^7$ m^2/m^3, curve 4 for $\Omega_0=9{,}6*10^7$ m^2/m^3).

The corresponding humidity intervals made (0,135÷0,185) for the first field and (0,225÷0,35) for the second one. Consequently, the plowing time can be determined by the spring drying of soil according to humidity measurements, if there are NTC curves for a given field.

4. Single integral energy criterion for soil estimating and their state estimation

The use of particular soil parameters to assess the "quality" of the soil and their application to solve specific geoecological problems of different directions can be replaced by a single integral evaluation criterion concerning the "quality" of soils and the external impacts on soil of natural and anthropogenic character (Sirotkin V.V., Vasyukov S.V. 2014, Sirotkin V.V. 2002, Sirotkin V.V., Sirotkin V.M., Vasyukov S.V. 2012, Vasyukov S.V., Vasyukov P.V., Sirotkin V.V .Cheboksary. 2013, Sirotkin V.V., Vasyukov S.V., Vasyukov P.V. 2014).

The general energy concept of the physical state of soils was proposed by A.D. Voronin (Voronin A.D. 1990). According to this concept, most soil properties change with the change of the liquid phase content, which changes the nature of water and soil solid phase interaction.

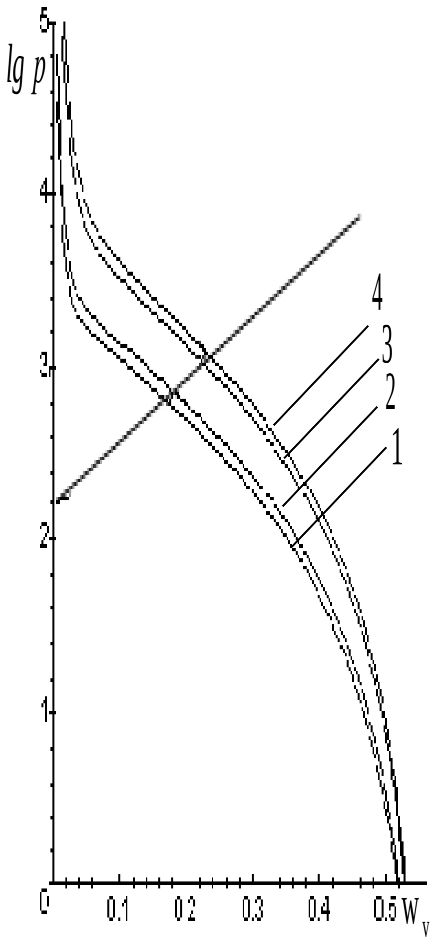

Fig.3. The crossing of NTC and the "ripeness" curve of soil

Since the system "solid-liquid" phase is in thermodynamic equilibrium, then, it is possible to judge the energy state of soil according to the basic hydrophysical characteristic of soil moisture.

With humidity change, the thermodynamic state of the system passes through a series of critical states corresponding to phenomenological constants and qualitative changes of the system physical-mechanical properties. Each of the critical states is represented by the equation connecting the equivalent pressure (the moisture potential value) and humidity. The moisture potential for the transition from water with a changed phase state to water with ordinary properties is described by the following equation:

$\lg p^1_m = 4.2 + 3W^1$, (6)

where p_m^1 is an equivalent pressure of a second-order phase transition, W' – mass humidity.

The state of the soil corresponding to the wilting moisture W^{11} of plants is described by the following equation

$lg\ p_m'' = 1,17+15W''$, (7)

where p_m'' is the equivalent pressure corresponding to this humidity.

The following equation

$lg\ p_m''' = 1,17+3W'''$. (8)

where p_m''' is the equivalent pressure corresponding to the "ripe" state of the soil.

The following equation has the following form:

$lgp_m^{1V} =1,17+ 1W^{1V}$. (9)

where p_m^{1V} is the value of the equivalent pressure, which corresponds to the moment when the capillary forces begin to prevail over the adsorption forces.

Finally, an equation of the form

$lgp_m^{V} =1,17$. (10)

corresponds to the state of moisture in a soil, when the influence of gravitational forces becomes noticeable.

From a phenomenological point of view: W^1 corresponds to the humidity of the capillary rupture; W^{11} corresponds to the wilting humidity of plants; W^{111} corresponds to the maximum molecular moisture capacity; W^{1V} corresponds to maximum adsorption moisture capacity; W^V corresponds to the maximum field water capacity.

Solving the equations describing the critical states with the equation of the basic hydrophysical characteristic for a particular soil, one can find moisture values corresponding to one or another critical state.

Since NTC equation has an analytical form, then the area of the bounded coordinate axis and NTC can be found by integration method within the moisture change on the state of complete saturation of soil pores with moisture to any of the moisture values corresponding to the critical states.

The physical essence of this area is the value of the system "solid phase-liquid phase" free energy per system volume unit - the specific volumetric free Gibbs energy corresponding to one or another critical state.

When this value changes during the impact on soil, this makes it possible to estimate the effect with respect to the difference in the values of specific volumetric free energy after and before the action to its initial value. This makes it possible to assess the influence of one or another effect on the change of plant growth conditions, and, consequently, to evaluate the impact itself. If the ratio has the sign "-", then it means that there have been changes in soil, adversely affecting the growth of plants, for example, during man-made soil compaction. Conversely, if the ratio has the sign "+", then there the soil loosening took place, favorably affecting the growth and the development of plants. Such statements are valid provided the specific soil surface is constant (which corresponds to reality) and does not exceed 0.7 with a volumetric porosity (the filtration becomes a "failure" with a higher porosity) (Ghanbarian, B., Allen, G.H., Sahimi, M., Ewing, R.P., Skinner, T.E. 2013).

The numerical values of the specific volumetric free energy for specific soils, found within the limits of humidity change from full saturation to the moisture of stable wilting of plants, calculated from the experimentally determined values of the specific surface and porosity within the conditions of soil equilibrium state (during spring time before processing or during autumn after harvesting) can be used as a single integral criterion.

A single integral criterion makes it possible to compare soils, and its numerical value determines their "quality". According to the analysis of the experimental data, the maximum value of this criterion was observed for leached chernozem on the territories under study. This indicates that this is the most valuable soil for the territory of Chuvash Republic. The analysis of long-term data on yields, on different soils, under the same climatic conditions, has shown that it correlates well with the values of a single integral criterion for soil estimation. Consequently, a single integral criterion can be used as an index determining the physical and hydrophysical properties of soils at their qualitative evaluation (Alex B. McBratney, Budiman Minasny, Raphael Viscarra Rossel. 2006).

4. CONCLUSIONS

The energy state of moisture is determined by the basic hydrophysical characteristic of soil (BHPC) - the relationship between the thermodynamic potential and humidity. The course of BHPC curve for a particular soil depends on the specific surface area and porosity.

It is customary to call BHPC as the relationship between humidity and moisture potential. This dependence is usually represented by the graph in the moisture-

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logarithmic coordinates of the potential.

5. SUMMARY

Using BHPC, it is possible to calculate the number of components introduced into soil in order to improve its water and physical properties. It is also possible to use BHPC for comparative (cadastral) assessment of various soils on agricultural lands and to determine the optimal terms of soil processing in a specific geographic region. It is also possible to use BHPC as a single integral energy criterion for the evaluation of soils and their qualitative state, primarily from the position of the geoecological approach.

БЛАГОДАРНОСТЬ (ACKNOWLEDGEMENTS)

The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University.

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