Variability of Soil Hydrophysical Parameters in Different Geomorphological Conditions of the Subboreal Zone of the Chuvash Republic

Sergey Vasyukov[1], *Dmitrii* Iakimovich[2], *Vyacheslav* Sirotkin[3], and *Bulat* Usmanov[3*]

[1]Federal Service for State Registration, Cadastre and Cartography in the Chuvash Republic, Cheboksary, 428009, Russia
[2]Chuvash State Agrarian University, Cheboksary, 428003, Russia
[3]Kazan Federal University, 5, Tovarisheskaya str, Kazan, 420097, Russia

Abstract. This paper analyses the hydrophysical parameters of soils and their variability, as well as soil moisture availability in relation to their geomorphological conditions in the subboreal zone of the Chuvash Republic. The research was carried out at three polygons, each including several sampling points in different geomorphological conditions. The authors analysed a number of indicators, including soil volume mass, solid phase density, soil porosity, soil filtration coefficient, specific volume surface of solid phase and soil moisture potential. The aforementioned data were used to construct basic hydrophysical characteristic (BHC) curves for each site. It was then possible to draw conclusions regarding the existence of notable changes in soil moisture availability for plants and soil hydrophysical properties in response to changes in absolute altitude and geomorphological conditions, as well as in relation to soil type.

1 Introduction

Numerous soil studies have proved that in most cases soil fertility of agricultural land is deteriorating due to inadequate agricultural practices, water erosion, insufficient or excessive application of fertilisers. The latter also leads to pollution of ground and surface waters or accumulation of chemical substances in dangerous concentrations in the soil.

Developing principles of agricultural land use that avoid such extremes is the main objective of the so-called precision farming concept, which aims to provide the necessary nutrients and moisture characteristics in the soil to support optimum plant growth and prevent soil degradation.

One of the main obstacles to the application of this concept is the heterogeneity of soil cover, often even within a single plot of land. As a consequence, even if it is technically possible to perform a wide range of analyses and determine soil fertility using different methods, most of them are rather labour-intensive. Consequently, it is necessary to study the variability of the soil indicators in the landscape context as well as and their interrelationship with the state of the soil cover.

* Corresponding author: busmanof@kpfu.ru

One of the research areas developing within the framework of the solution of the soil degradation, is study of changes in hydrophysical indicators of soil cover. With increasing soil erodibility such hydrophysical indicators as specific and volumetric mass, maximum hygroscopicity, wilting moisture increase, porosity and active moisture range decrease [1].

The most conservative soil parameters, which largely determine its hydrophysical properties, are its density and specific surface area of solid phase [2-3].

The thermodynamic method is of great importance. With the help of energy functions it is possible to give a strict quantitative assessment of the moisture state in the soil [4-5]. The most informative characteristic determining the energy state of moisture in agricultural soils is the basic soil hydrophysical characteristic (BHC) [6]. The nature of the BHC curve for a particular soil sample depends directly on the specific volume surface and porosity of the soil [7], and this relationship can be used to solve many problems of soil quality research and regulation of soil parameters for optimal use, primarily for agricultural purposes.

Also problematic is the fact that there is no strict mathematical regularity between soil moisture potential and soil moisture content. Rode (1965) wrote that how much easier life would be if the relationship between suction pressure and soil moisture were linear [8]. In general, it can be noted that the mechanisms of water "binding" in soils are the most important factor of soil fertility and the main object of research in soil hydrophysics [9], they were the object of research of such scientists as B.V.Deryagin, S.V.Nerpin [10].

Thus, to date, the current state of research in the field of studies of soil hydrophysical characteristics and their relationship with land cover degradation is somewhat contradictory. Apparently, there is a need for standardisation of soil sampling and analyses, as well as geographical localisation for specific types and subtypes of zonal soils. In any case, scientific research confirms the need for further study of soil properties with increasing geographical coverage of the studied soils.

Hydrophysical parameters of soil obtained both empirically (in situ) and as a result of desktop processing and theoretical calculations, which should be based on statistically significant and reliable material from field studies, can be used to create a database of structural subdivisions of the landscape. Therefore, to obtain objective information, it is necessary to conduct multi-temporal studies on similar landscapes. Hydrophysical parameters are spatially highly variable, so to obtain reliable data, in addition to analyzing the natural-territorial complexes of the region, we need long-term results of quantitative and qualitative field stationary studies. As a rule, the reference sites with the most characteristic landscapes are selected for these studies, and it is this circumstance that determined the choice of the studied sites.

A series of studies were conducted to investigate the impact of geomorphological conditions on soil hydrophysical parameters and soil moisture availability in several landscape-soil areas of the subboreal zone of the Chuvash Republic. These studies were conducted on different areas of slopes under agricultural cultivation (Figure 1).

The objective was to determine the differentiation of hydrophysical parameters and soil moisture availability due to changes in geomorphological conditions of the area. It is of great importance to identify these patterns, as they allow considering the differences in soil moisture availability for agricultural plants when placing cultures with varying "sucking power" in order to optimise their development without the use of artificial irrigation. This indicator is very important for proper planning of planting of different types of crops and for explaining the regularities of vegetation distribution along the profile. Up-to-date data on hydrophysical parameters can be used in the selection of agricultural and forestry land use and in precision farming.

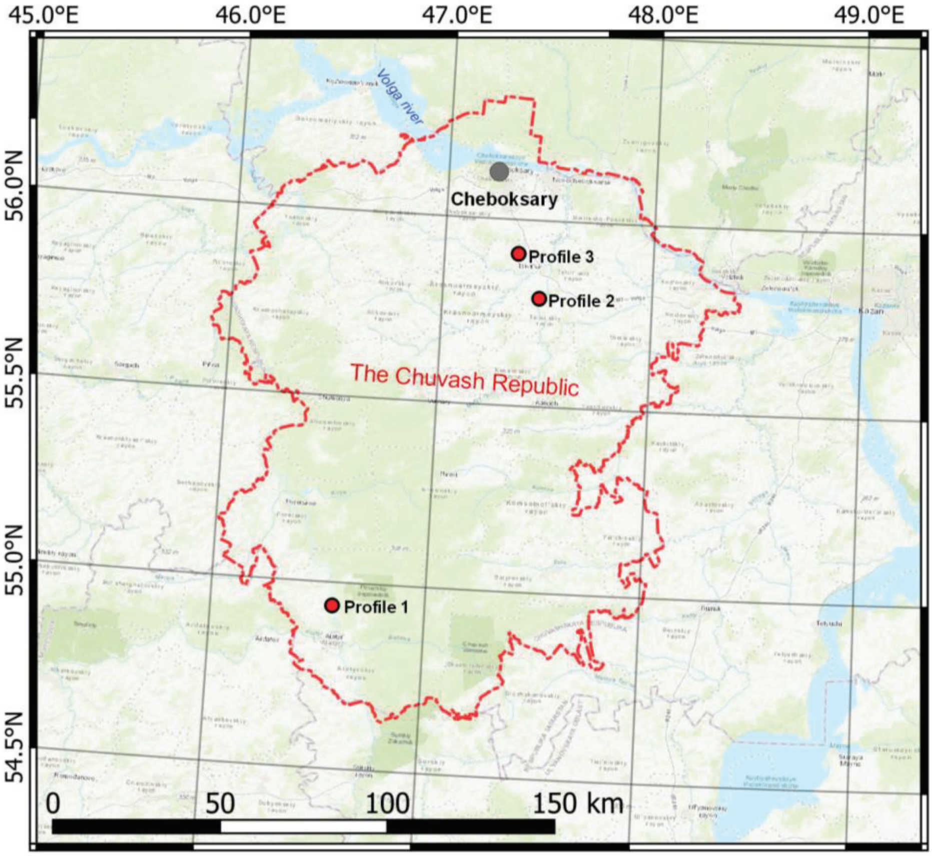

Fig. 1. Location of the study areas.

2 Materials and Methods

To determine hydrophysical parameters, undisturbed soil samples were collected in different geomorphological elements of the slope. The following parameters were determined: Soil volume mass, Soil solid phase density, Soil porosity, Soil filtration coefficient, Specific volume surface of soil solid phase, Soil moisture potential. Visual and morphological description of soil cover was also carried out by making full profile soil transects.

Profile 1. Yavlei village, Alatyrsky municipal district, Chuvash Republic. Samples were taken within the watershed (site 1), slope (site 2) and floodplain areas (sites 3 and 4) of the Sura River. Soil cover in the sampling area is represented by leached chernozems (watershed and slope section) and alluvial meadow saturated soils (floodplain section). The hypsometric elevations of the sample plots are (Baltic altitude system): 1 site – 203 m, 2 site – 147 m, 3 site – 84 m, 4 site – 80 m.

Profile 2. Pervoye Chemercheevo village, Tsivilsky municipal district, Chuvash Republic. Samples were taken within the watershed (site 1) and slope (site 2) of the left bank of the Maly Tsivil River. Soil cover in the sampling area is represented by ploughed dark grey forest soils. Hypsometric elevations of the samply plots are (Baltic altitude system): 1 site – 122 m, 2 site – 88 m.

Profile 3. Tebikasy village, Tsivilsky municipal district, Chuvash Republic. Soil samples were taken within the watershed (site 1) and slope (site 2) area on the left bank of the Pozhenarka River. Soil cover in the is represented by ploughed light grey forest soils. Hypsometric elevations of the sample plots are (Baltic altitude system): 1 site – 137 m, 2 site – 108 m.

As a result, the curves of the basic hydrophysical characteristics were obtained for each study site according to the known methods [3]. Analysis of the BHC curves at the study sites is the basis for calculating the availability of soil moisture for agricultural plants and the functioning of natural ecosystems. According to these curves, it is possible to determine the irrigation rates of plants and the state of oppression of aboveground plant communities regarding soil moisture availability.

3 Results and Discussion

Hydrophysical parameters on different soils and slopes within the subboreal zone of the Chuvash Republic show a similar pattern of changes depending on the absolute elevation and slope inclination. The most informative picture is given by indicators of soil volume mass, it increases with decreasing absolute height and increasing slope steepness. This is due to erosion washout and migration of silty soil particles down the slope.

The indicators of specific volume surface of solid phase and soil moisture potential are also very informative, these indicators are interrelated, they decrease with reduction of absolute elevation and increase of slope inclination. It is also connected with erosion processes and mass transfer of soil particles with lower specific volume surface area of soil solid phase. Moisture parameters do not change much, as they strongly depend on atmospheric precipitation and current soil moisture, due to this fact they are not analysed in this article, although they were also determined during the studies.

Analysis of curves of basic hydrophysical characteristics (Figure 2) showed that there are significant differences between plots with different geomorphological conditions. Taking into account that the most of agricultural plants experience stress condition at exceeding the soil moisture potential in the range from 0.16 to 1 atm, which in decimal logarithm makes the range from - 0,796 to 0. The general pattern is as follows:

- Soil moisture availability increases with reduction of absolute elevation, i.e. downslope, as on leached chernozems (by 5-7%), and in alluvial-meadow saturated soils (by 10-12%), as well as in ploughed dark grey forest soils (by 50-55%). The exception to this regularity is the profile of ploughed light grey forest soils in the area of Tebikasy village, Tsivilsky municipal district, Chuvash Republic. There is a decrease in soil moisture availability with slope decrease (by 7-10 %). This is explained by strong technogenic degradation of this slope section, in this area agricultural vegetation was strongly depressed and represented mainly by weed vegetation (Wormwood bitter and Pizhma medicinal), due to significant compaction of the upper soil horizon by agricultural vehicles.
- Soil moisture availability in absolute terms in leached chernozems is higher than in alluvial-meadow saturated soils (on average by 10%), dark grey (10-15%) and light grey forest soils (15-20%).
- The step of change of soil moisture availability with terrain elevation and geomorphological conditions in leached chernozems is lower than in alluvial meadow saturated (by 5%), dark grey (by 10%) and light grey (by 15%) soils.

https://doi.org/10.1051/bioconf/202516002025

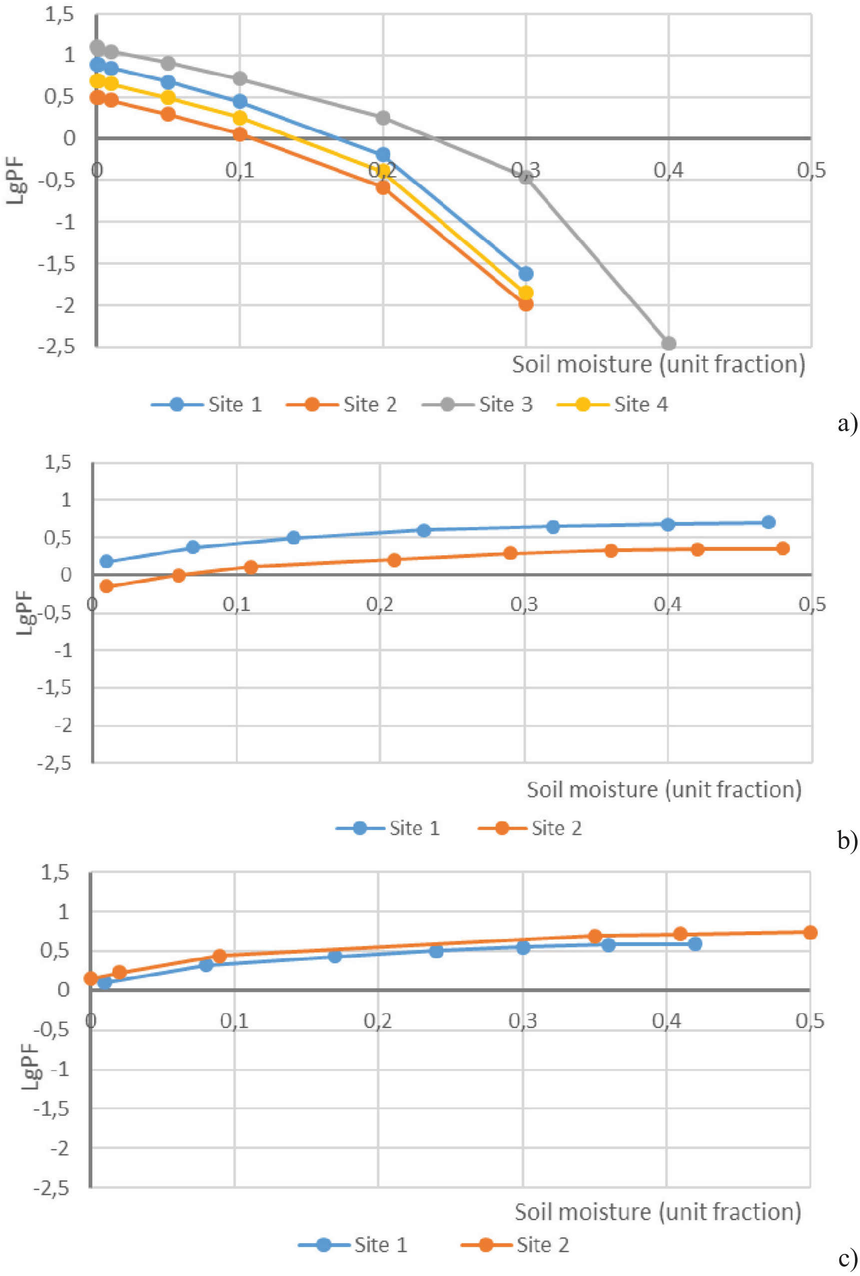

Fig. 2. Main hydrophysical characteristic curve at Profile 1. Yavlei village (a), Profile 2. Pervoye Chemercheevo village (b), Profile 3. Tebikasy village (c).

4 Conclusions

The results of the study indicate that changes in absolute altitude and geomorphological conditions result in noticeable changes in soil moisture availability for plants and the hydrophysical properties of soils. Furthermore, there is a significant difference between different types of soils. The general pattern of changes shows that with increasing slope steepness the availability of soil moisture for agricultural plants decreases, the hydrophysical parameters of soils change towards unfavorable for plant growth. There is a significant change of soil moisture availability in absolute values in the direction from chernozems to light gray forest soils, i.e., the change of absolute values of soil moisture availability has a latitudinal-zonal character, decreasing in the direction from steppe zone to boreal zone. It is connected with change of soil particles structure and decrease of their specific volumetric surface due to soil cover genesis. This circumstance should be taken into account when assessing the state of natural and anthropogenic ecosystems, and it is especially important to take it into account when planning agro-ecosystems, conducting agricultural activities and taking measures to reduce landscape degradation from erosion and deflation.

Acknowledgement

The work is carried out in accordance with the Strategic Academic Leadership Program "Priority 2030" of the Kazan Federal University of the Government of the Russian Federation.

References

1. B. Ghanbarian, A.G. Hunt, M. Sahimi, R.P. Ewing, T.E. Skinner, Soil Science Society of America Journal, **77**, 6 (2013)
2. R.D. Stewart, D.E. Rupp, M.R. Abou Najm, J.S. Selker, Soil Science Society of America Journal, **17**, 3 (2013)
3. S.Vasyukov, V.Sirotkin, Proc. IAHS, **367** (2015)
4. G.Kraus, J.W. Ross, L.A. Gerifalco, J. Phys. Chem., **57** (1953)
5. V. Golosov, O. Yermolaev, L. Litvin, N. Chizhikova, Z. Kiryukhina, G. Safina, Land Degr. and Devel., **29**, 8 (2018)
6. S.V. Vasyukov, V.V. Sirotkin, B.M. Usmanov, S.A. Toguzov, D.N. Iakimovich, L.G. Akhmetzyanova, Application of UAV and spectrometric survey results to determine agrochemical parameters of zonal soils used in agriculture (East of European Russia), in Proc. SPIE 11856, Remote Sensing for Agriculture, Ecosystems, and Hydrology, 11856Z (2021)
7. E. Saljnikov, L. Mueller, A. Lavrishchev, F. Eulenstein, Advances in Understanding Soil Degradation (Springer, Switzerland, 2022)
8. A.A. Rode, Fundamentals of the soil moisture doctrine (Gidrometeoizdat, Leningrad, 1965)
9. A. Gafurov, A. Sharifullin, Proc. IAHS, **381** (2019)
10. N.A. Muromtsev, Bulletin of Moscow University. Series 6: Biology, soil science, **2** (1972)