Byulleten Pochvennogo instituta im. V.V. Dokuchaeva. 2014. Vol. 77.

THE USE OF NDVI PROFILES FOR ASSESMENT QUALITY OF ARABLE LANDS (EXEMPLIFIED BY THE BAKSAN REGION IN KABARDINO-BALKARIA)

© 2015 I. Savin[1,2], E. Tanov[2], S. Kharzinov[3]

[1]V. V. Dokuchaev Soil Science Institute, 119017, Moscow, Pyzhevskii per., 7
e-mail: savigory@gmail.com
[2]Peoples' Friendship University of Russia, 117198, Moscow, Miklukho-Maklaya, Str. 6
e-mail: ehldar-tanov@rambler.ru
[3]Kabardino-Balkarsky NIISH, 360024, Russia
e-mail: kharzinov83@mail.ru

A new approach for assessing the quality of arable lands was developed as based upon MODIS-derived satellite data. The essence of the approach consists in an expert analysis of NDVI curves derived separately for different crop groups in the last 10–12 years as well as the interannual variability of the NDVI seasonal maximum, whose value was used as an indicator for the crop status and yield on different plots. The nature of NDVI curves allowed expertly classifying the groups of winter, early spring and late spring crops. The approach to estimating the quality of arable lands was approved on the example of the Baksan region in Kabardino-Balkaria. All the arable lands have been comprehensively analyzed in the region, the mask of which was created by visual interpretation of field boundaries using LANDSAT satellite imagery. The temporary NDVI profiles were obtained by the satellite service "VEGA". Based upon the given method all the plots in the region were classified according to the quality of arable lands. The obtained data may be used in cadastre surveys for objective estimate of lands and optimal arrangement of the main agricultural crops in this Republic, being applicable in the other regions of the Russian Federation.

Keywords: land evaluation, NDVI, satellite service "VEGA", arable lands, Kabardino-Balkaria.

INTRODUCTION

According to legal rules for price formation in the Russian Federation the cadastre survey with the view of estimating the land quality serves as a base for land taxation. However, in a number of regions the results of cadastre surveys are not sufficiently used due to inappropriate organization and the absence of wise decisions in this very complicated process. Within the last 10 years the land tax became increased by 4.6 times and today it is completely determined by results of the State cadastre estimation of lands. In view of this, "the error price" of taxing-masters was repeatedly increased as well.

Methodical instructions for the State cadastre estimation of all the land categories were agreed and adopted in the period from 2001 to 2003. These documents together with methodical recommendations to determine the market cost of lands adopted on 06.02.2002 (No. 568-p) were considered as a methodological basis for estimating the land quality in Russia.

The approaches used for elaborating the above methodical instructions revealed several shortages described in many publications, being generalized as the following [7]. (1) The actual crop yield is illegally used instead of potential (normative) one. (2) The results of cadastre estimates are not correlated between those obtained in different regions. (3) Climatic conditions as well as the land suitability and a variety of crops were not taken into consideration.

New methodical instructions for the State cadastre survey with the view of estimating the agricultural lands have been adopted by the Ministry of Economic Development (No. 445) in 2010. Instead of analyzing the actual data about crop yields and expenditures in the last years the indices of normative productivity (in dependence on soil properties) and normative expenditures are proposed to use as based upon technological maps.

As distinct from the previous methods a list of soil properties specifying the land estimate was enlarged. However, using the given method a problem is arisen as related to the absence of actual soil maps and information on some properties of soils and their degradation degree, what restricts the application of this approach in practice. To avoid shortcomings, the information on the sustained crop yield could help as an indirect index for the quality of arable lands. In spite of the fact that the given approach intends to use the normative yield, to our viewpoint, the estimate of real crop yield obtained for several years permits to speak more exactly about the quality of arable lands, because just this yield reflects reliably all the natural and anthropogenic conditions with account of its variability. But it is very difficult to obtain the data about the real yield in field due to labor-consuming nature, great expenditures and impossible retrospective analysis of crop yield.

The satellite technologies open new possibilities to organize the monitoring over the crops, to determine a crop type and to estimate the yield, the soil state and effects of extreme factors [3–5, 16, 20, 22]. For this purpose a huge volume of satellite information should be analyzed what is rather difficult to do. In the last time new geoportal technologies have been elaborated to simplify the task and to make this analysis more accessible for any user.

The present paper is dealing with the specific of using the NDVI (Normalized Difference Vegetation Index) time profiles for estimating the crop state obtained by the satellite service "VEGA".

OBJECTS OF RESEARCH AND METHODS

The objects of research are arable lands in the Baksan region of Kabardino-Balkaria (Fig. 1). This region is located in central part of Kabardino-Balkaria occupying 82 958 ha or 7% of the total area in this Republic.

Fig. 1. Location of the Baksan region.

According to the natural-agricultural regionalization two zones are distinguished there including the piedmont and steppe ones with the moderately continental and moderately humid climate.

The soil cover is represented by a great diversity of soils predominating by pre-caucasian, ordinary, typical and leached chernozems. Dominant are clay and heavy clay soils; the loamy, light-loamy and loam-sandy soils are also observed being frequently eroded on slopes. Due to such a diverse soil cover the yield of agricultural crops is varying on different fields. Nevertheless, the favorable combination of soil-climatic conditions is conducive to the development of agricultural production in this region. In 2010 the agricultural area was estimated at 80% or 66 000 ha from the total territory of the region. The arable lands occupy about 35000 ha (54%), hay lands – 15000 ha (22%), pastures – 14000 ha (21%) and perennial plantations – about 2000 ha or 3%. The main agricultural crops are the winter wheat, barley, maize, sunflower and potato.

At the preliminary stage of this study a vector mask has been created to show the arable plots in this region by using the satellite Landsat 5 TM data obtained in 2010. The mask was created by means of the software IL WIS 3.3 (http://www.ilwis.org) and manual vectorization of plots boundaries. Only the plots were identified, which have been once ploughed within 2005–2012. They were visually recognized by using Landsat data.

The satellite service “VEGA” helped to determine the weekly NDVI (Normalized Difference Vegetation Index) values for every field during 2001–2012 [1, 6]. This index was extracted for a point in central broad part of every arable plot.

Based upon an expert analysis of NDVI profiles for each plot and vegetation season an attempt was made to detect a crop type using such indicators as the beginning of the vegetation season, NDVI seasonal maximum, the rate of increasing the NDVI value in the spring and its decreasing in the autumn, the flat area and picks expressed in the NDVI time profile, the NDVI increasing in the autumn period before the snow cover.

The NDVI seasonal maximum was determined for every profile of each crop (crop group) in order to use this value as an indicator of above ground phytomass in the period of crop flowering. There is a huge amount of publications to show the possible use of NDVI seasonal maximum as an indicator of above ground phytomass [19]. NDVI is frequently used for forecasting the yield of crops including those cultivated at the territory under study [11, 10, 17, 14, 18, 23, 24, 15, 8, 5, 21]. Just this fact permits to consider NDVI as an indicator of crop state and yield.

It is known that NDVI is not an ideal index of the crop state and above ground phytomass. This is associated with the so-called “saturation” of this index in case of a higher plant canopy and the influence exerted by spectral reflectivity of the soil surface when the crop canopy is rather low [12, 13, 9]. As a rule, NDVI is “saturated” due to the plant stand and very high crop yield, what is not characteristic of the studied region. The effect of the soil reflectivity on the NDVI value is theoretically possible for tilled crops and at the early stages of phenological development of crops. In using the NDVI seasonal maximum it is likely to be of minor significance. At the territory of the given region dominant are chernozems with the high humus content in the topsoil; they are frequently eroded on slopes [2]. In this context, the soil background has the different influence on the NDVI value in watersheds and on slopes. The major arable fields are located in watersheds and the impact rendered by the soil background on the NDVI value has to be of one type without any consequences for the accuracy of this approach.

Having analyzed the NDVI seasonal maximum, it was possible to determine its inter-annual variability in every crop group and the average value for every group on each arable plot. All the plots were grouped according to the average NDVI value for each crop (crop group). The estimate of the land quality on every plot was made with account of average values of NDVI seasonal maximum and its inter-annual variability.

RESULTS AND DISCUSSION

At the studied territory 576 arable plots were distinguished predominating by those with acreage of 20 to 120 ha (Fig. 2 and 3). It means that the plot size is quite sufficient for analyzing the crop state using MODIS-derived spatial resolution of about 6.25 ha. The NDVI curves for every plot allowed identifying the crop groups including the early summer and winter, late summer crops. As it turned out, for 12 years

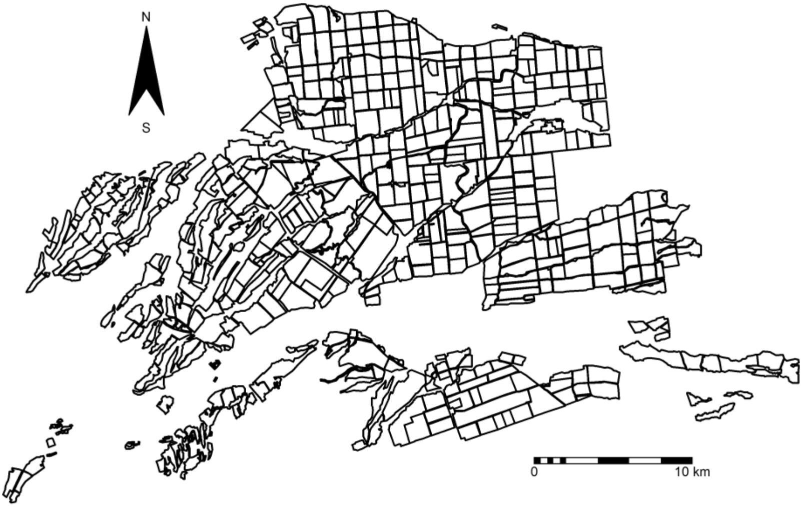

Fig. 2. Boundaries of arable plots in the Baksan region in 2010.

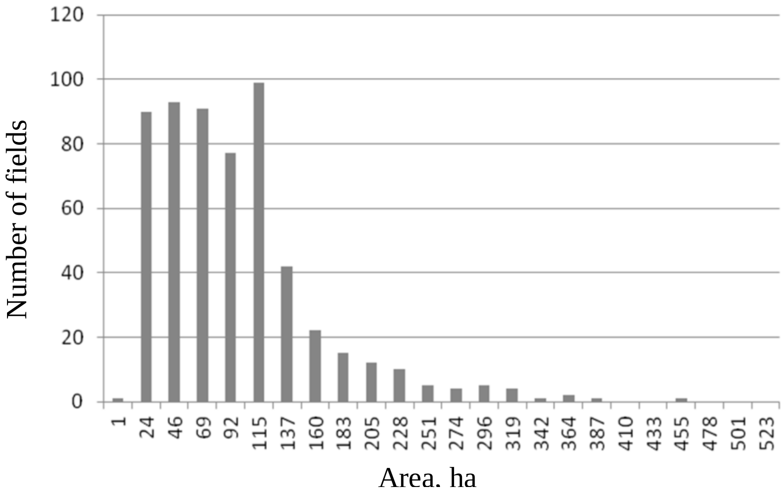

Fig. 3. Histogram for the area of arable plots in the region under study.

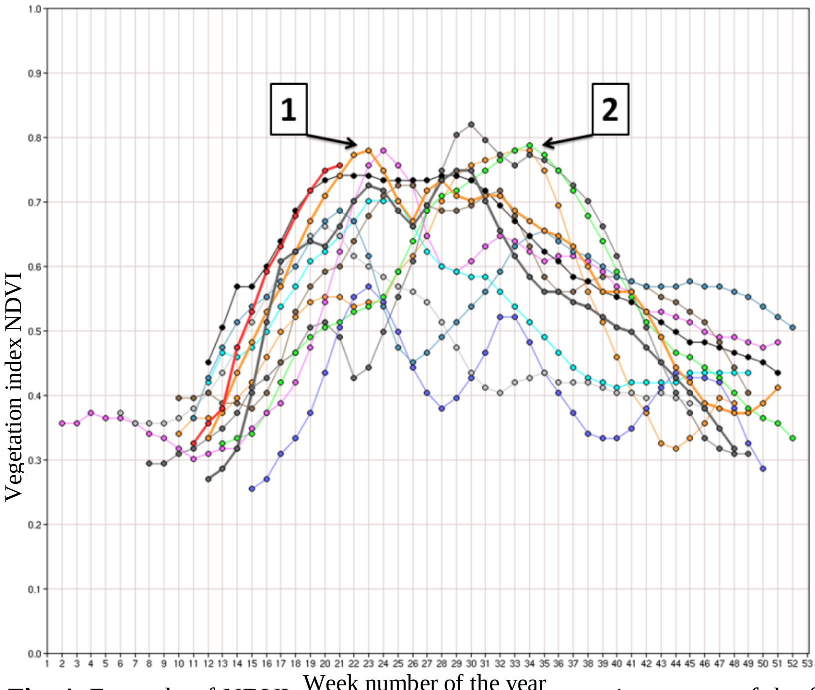

Fig. 4. Example of NDVI curves for one of the fields (1 – curves of the first group, 2 – curves of the second group).

Fig. 5. Fields with different NDVI value averaged for several years (the lighter is the color, the higher is the index value; black color – no data).

Fig. 6. Fields with NDVI inter-annual variability (gray color – high variability, white color – low variability. Black color – no data).

2–3 crops practically on all the fields cannot be referred to one of these groups (Fig. 4). The share of fields occupied by early winter and late winter crops seemed to be equal but in perspective the alternation of years for crops of one or another group may serve as a basis for identifying the crop rotation on plots.

A comprehensive analysis of the NDVI seasonal maximum for every plot showed that its average value for several years ranges from 0.6 to 0.9, what permitted to divide the plots into the following groups: higher than 0.8 (very high yield), 0.75–0.79 (high yield), 0.70–0.74 (average yield), 0.65–0.69 (low yield) and 0.60–0.64 (very low yield). The seasonal maximum value for every crop group is varying in different years to a greater extent (standard deviation is from 0.01 to 0.1). According to this deviation the plots were divided into the group with a higher variability (standard deviation – 0.05) and the other group with the variability less than 0.05 (Fig. 6).

Thus, a conjugate analysis of these data allowed classifying the plots according to the level of their productivity with account of the crop yield using the NDVI average value as an indicator as well as its inter-annual variability. 10 classes were recognized to show how is deteriorating the land quality and hence the crop state on plots as indirect characteristics of the soil fertility

1v class – very high yield with inter-annual variability;
2 class – high yield without inter-annual variability;
2v class – high yield with inter-annual variability;
3 class – average yield without inter-annual variability;
3v class – average yield with inter-annual variability;
4 class – low yield without inter-annual variability;
4v class – low yield with inter-annual variability;
5 class – very low yield without inter-annual variability;
5v class – very low yield with inter-annual variability.

As seen from Fig. 7, there are common regularities in distributing the plots of one class. Such plots are predominated, for example the yellow plots in central and southwestern part of the region, the orange plots – in the south-east of this region. The light-green plots occupy the major part at the southwestern territory. It serves as evidence that the fields are estimated according to their fertility what coincides with changing the natural conditions (changes in relief, climate and soils). It is worth emphasizing that the fields adjacent to each other may

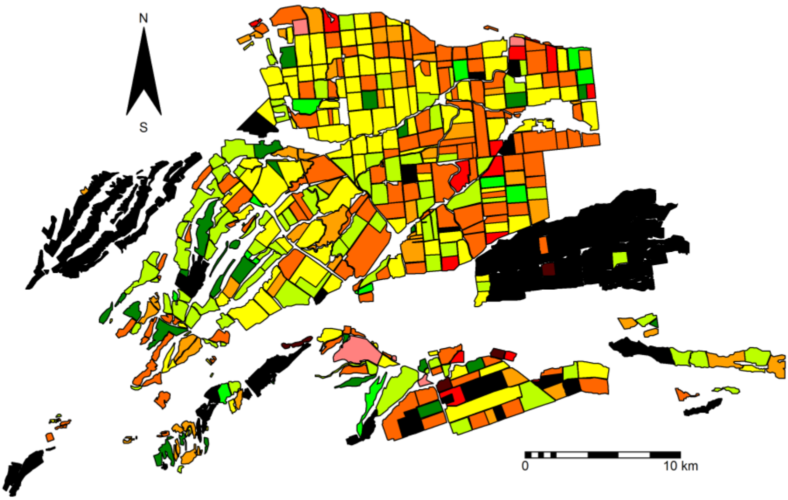

Fig. 7. Classification of arable plots according to the land quality (the more green – the better; the more red – the worse).

be referred to different classes. This is connected with different crop management practices or different level of fertilization. Hence, the used approach allowed classifying all the plots according to their actual fertility, i.e. the land quality.

CONCLUSION

Thanks to the satellite service “VEGA” it was possible to obtain the information on the crop state which allowed classifying the majority of arable plots according to their actual fertility. The given information can be used for cadastre estimating the land quality in the given region and may be useful for the other regions with the vast area of arable plots. The NDVI curve for small-sized plots is highly affected by the ground cover of adjacent areas, what decreases the quality of the obtained results.

At the studied territory the NDVI seasonal maximum permitted to identify the plots with winter crops and those covered by early summer cereals as well as a group of late crops containing some different crops. It was impossible to distinguish them more exactly on the basis of analyzing the seasonal NDVI time profile. Probably, this is explained by the insufficiently informative seasonal dynamics of the vegetation index (NDVI). Future studies are urgently required to elaborate a qualitative and more formalized approach to interpretation of agricultural crops.

Acknowledgment. Many thanks to the department of technologies for satellite monitoring in the Institute of Space Research of Russian Academy of Sciences for the satellite service “VEGA”.

REFERENCES

1. Lupyan E.A., Savin I.Yu., Bartalev S.A., Tolpin V.A., Balashov I.V., Plotnikov D.E. Satellite service of monitoring the state of vegetation (“Vega”), *Sovremennye problemy distantsionnogo zondirovaniya Zemli iz kosmosa*, 2011, Vol. 8, No. 1, pp. 190–198.
2. Pochvennaya karta Kabardino-Balkarskoy SSR. Maschtab 1 : 200000 (Soil *Map of Kabardino-Balkarskaya SSR*, Scale 1 : 200000, Moscow, GUGK, 1985.
3. Savin I.Yu. Open soil surface brightness as a direct sign for soil recognition on LANDSAT images, *Bulleten Pochvennogo instituta im. V.V. Dokuchaeva*, 2013, No. 71, pp. 52–64.

4. Savin I.Yu., Simakova M.S. Satellite technologies for soil inventorying and monitoring in Russia, *Sovremennye problemy distantsionnogo zondirovaniya Zemli iz kosmosa*, 2012, Vol. 9, No. 5, pp. 104–115.
5. Savin I.Yu., Bartalev S.A., Lupyan E.A., Tolpin V.A., Khvostikov S.A. Crop yield forecasting based on satellite data: possibilities and perspectives, *Sovremennye problemy distantsionnogo zondirovaniya Zemli iz kosmosa*, 2010, Vol. 7, No. 3, pp. 275–285.
6. Tolpin V.A., Balashov I.V., Lupyan E.A., Savin I.Yu. Satellite service "Vega", *Zemlia iz Kosmosa*, 2011, Release 9, spring, pp. 32–37.
7. Fomin N.P., Sapozhnikov P.M. Novye podhody k gosudarstvennoi kadastrovoi ozenke zemel selskohoziaystvennogo naznachenia *New approaches to the state cadaster estimation of the earth of agricultural designation* [the date of publication 20.10.2010]), http://www.valnet.ru/m7.phtml.
8. Bala S.K., Islam A.S. Correlation between potato yield and MODIS-derived vegetation indices, *International J. of Remote Sensing*, 2009, Vol. 30, Iss. 10, pp. 2491–2507.
9. Baret F., Guyot G. Potentials and limits of vegetation indices for LAI and APAR assessment, *Remote Sensing of Environment*, 1991, Vol. 35, pp. 161–173.
10. Benedetti R., Rossinni P. On the use of NDVI profiles as a tool for agricultural statistics: the case study of wheat yield estimate and forecast in Emilia Romagna, *Remote Sensing of Environment*, 1993, Vol. 45. pp. 311–326.
11. Bouman B.A.M., Uenk D., and Haverkort A.J. Estimation of ground cover of potato by reflectance measurements, *Potato Research*, 1992, Vol. 35. pp. 111–125.
12. Elvidge C.D., and Lyon R.J.P. Influence of rock-soil spectral variation on assessment of green biomass, *Remote Sensing of Environment*, 1985, Vol. 17, pp. 265–279.
13. Huete A.R., Jackson R.D., and Post D.F. Spectral response of a plant canopy with different soil backgrounds, *Remote Sensing of Environment*, 1985, V. 17, pp. 37–53.
14. Groten S.M.E. NDVI crop monitoring and early yield assessment of Burkina Faso, *International J. Remote Sensing*, 1993, Vol. 14(8), pp. 1495–1515.
15. Liu W.T., and Kogan F. Monitoring Brazilian soybean production using NOAA/AVHRR based vegetation condition indices, *International J. of Remote Sensing*, 2002, V. 23(6), pp. 1161–1179.
16. Medvedeva M.A., Savin I.Yu., and Isaev V.A. Determination of Area of Drought-Affected Crops Based on Satellite Data (Exemplified by Crops in Chuvashia in 2010), *Russian Agricultural Sciences*, Vol. 38, No 2, 2012, pp. 121–125.

17. Quarmby, N.A., Milnes M., Hindle T.L., and Silicos N. The use of multitemporal NDVI measurements from AVHRR data for crop yield estimation and prediction, *International J. of Remote Sensing*, 1993, Vol. 14, pp.199–210.
18. Rasmussen, M.S. Operational Yield forecast using AVHRR NDVI data: reduction of environmental and inter-annual variability, *International J. Remote Sensing*, 1997, Vol. 18(5). pp. 1059–1077.
19. Rembold F., Atzberger C., Savin I., Rojas O. Using low resolution satellite imagery for yield prediction and yield anomaly detection, *Remote Sensing*, 2013, Vol. 5, No. 4, pp. 1704–1733.
20. Remote Sensing Support to Crop Yield Forecast and Area Estimates, *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* Vol. XXXVI, No. 8/W48 ISPRS WG VIII/10 Workshop. Stresa, Italy 2006.
21. Saravanan S. Estimating Yield of Irrigated Potatoes Using Aerial and Satellite Remote Sensing, *All Graduate Theses and Dissertations*, 2011, Paper 1049.
22. Savin I.Yu., and Nègre T. Agro-meteorological Monitoring in Russia and Central Asian Countries OPOCE EUR 22210EN, Ispra (Italy), 2006, 214 p.
23. Unganai L.S. and Kogan F.N. Drought monitoring and Corn yield estimation in Southern Africa from AVHRR data, *Remote Sensing of Environment*, 1998, V. 63, pp. 219–232.
24. Yang C., Everitt J.H., Bradford J.M., and Escobar D.E. Mapping grain sorghum growth and yield variations using airborne multispectral digital imagery, *Transactions of ASAE*, 2000, V. 43(6), pp. 1927–1938.

A COMPREHENSIVE ANALYSIS OF THE MICROBIOME IN THE COMPLETE PROFILE OF VIRGIN LIGHT-COLORED SOLONETZ SOIL AT THE TERRITORY OF DZHANYBEK RESEARCH STATION

© 2015 T. I. Chernov, A. K. Tkhakakhova, M. P. Lebedeva, O. V. Kutovaya

V.V. Dokuchaev Soil Science Institute, 119017, Moscow, Pyzhevskii., 7, bld. 2
e-mail: chern-off@mail.ru

Under study was the microbiome structure in virgin light-colored hydromorphized solonetz soil by using molecular-genetic (analysis of prokaryotic metagenome) and cultural methods. It is shown that the prokaryotic diversity (according to OTU amount, Shennon index and Chao1) is gradually decreasing downwards the soil profile. Common features of microbiomes are found to be in the solonetz horizon and the lower part of the profile (low biodiversity, some *Proteobacteria* are dominant). A higher share (almost 20% of the community) of *Archaea* from the group of *Thaumarchaeota* is observed in the horizon overlying the solonetz one.

Keywords: solonetz soil, metagenome, soil microorganisms, pyrosequencing, 16S рРНК, Archaea, biodiversity.

INTRODUCTION

Microbiological complexes of arid soils including saline ones have been so far examined insufficiently and some problems relating to the diversity, functioning and variability of microbial communities in arid soils are still far from being understood. As a rule, the uppermost soil horizons characterizing by main biochemical processes associated with the organic matter transformation are of interest for researchers [5, 10]. However, the lower horizons of arid soils which are poor in the organic matter and frequently salt-affected need to be thoroughly studied from the viewpoint of identifying the factors determining the structure of microbial communities in soil. In literature there is no information on the analysis of microbiome along the profile of arid soils to the depth of 150 cm. In view of this, an attempt was undertaken to study the microbiome in the profile of virgin solonetz soil at the territory of Dzhanybek Research Station of Forestry Institute of Russian Academy of Sciences.

This paper presents a comparative analysis of microbial communities along the profile of virgin light-colored hydrometamorphized solonchakous solonetz by using traditional methods of seeding on nutrient media and molecular-biological methods – analysis of prokaryotic metagenome.

OBJECTS OF RESEARCH AND METHODS

Dzhanybek Research Station is located within the subboreal belt in the northern part of the Pre-Caspian lowland in the Volga-Ural interfluve area elevated by 25–28 m. The low precipitation (250–350 mm) and the higher evaporation (about 1000 mm) are characteristic of the semi-arid climate. The territory under study is a closed plain confined to brown loess-like carbonate heavy loams underlying by clay with loam-sandy and sandy interlayers at a depth lower than 15 m [6]. The groundwater level is 4–5 m [7].

The object of research is a solonetz profile (pit 7M-13) at the virgin territory of Dzhanybek Research Station (49.39943^{o} N, 46.81062^{o} E). The vegetation is represented by *Poa bulbosa*, *Lepidium perfolliatum*, *Artemisia australica*, *Kochia prostrate;* the soil is effervescent at the depth of 15 cm; the groundwater level – 4.74 m. The morphological, micromorphological and chemical properties of this soil profile have been studied and published earlier [3]. In the course of our studies the following soil horizons were described:

AYEL, 0–7(10) cm – light-pale-gray, structure is changing along the profile, being flake and lens-like in the upper part and crumby downwards the profile; dry, light-loamy fine-silt, slightly compacted; the plant roots in the kind of rosettes, gradual transition, wavy boundary.

BSN, 7(10)–14 cm – pale-whitish sites in the upper part of dense prismatic soil particles; dry; abundant plant roots of different size; porous, medium loamy; fine iron coatings and patches; transition according to density, coloring and structure.

BSNbc, 14–24(26) cm – coffee-like in color, very dense; prismatic structure; heavy loamy, fresh; gradual transition according to coloring and density.

BSNs,bc, 24(26)–33(36) cm – brown; coffee-like coatings at the edges of soil particles; prismatic structure; dense to a lesser extent; medium loamy, fresh; gypsum-bearing veins and fine carbonate spots; transition according to occurrence of a great amount of salt pedofeatures.

NCAs, 33(36)–57 cm – uneven coloring: in some sites a great amount of white and pale spots and patches against the brown background – gypsiferous and carbonate pedofeatures; dense to a lesser extent and more fresh as compared to the overlying horizon; a classical pseudosandy medium loamy horizon [6], instable lumpy structure; transition according to coloring and the decreased amount of salt pedofeatures.

BCs, 57–100 cm – yellowish-brown; more wet and compact to a lesser extent; lumpy structure with rare rounded patches comprising fine gypsum crystals of 1 cm in diameter; medium loamy; wave boundary; transition according to decreasing the amount of salt patches.

BC, 100–150 cm – light-yellowish-pale; wet medium loamy; instable lumpy structure; rare rounded salt patches.

The soil under study is classified as a virgin light-colored hydromorphized solonetz (Soil Classification of Russia, 2004) and Episalic Solonetz (WRB, 2006).

The soil samples taken in the middle-profile genetic horizons were used for the molecular-biological analysis and storage at –70°C. Their preparation included the following procedures. DNA isolation from 0.5 g of soil after mechanical destruction with the use of small glass balls in the extracting buffer solution containing 350 pL of solution A (sodium-phosphate buffer – 200 mM, isocianate guanidine – 240 mM, pH – 7.0), 350 pL of solution B (Tris-HCl -500 mM, SDS – 1%, pH – 7.0) and 400 pL of phenol with addition of chloroform (1 : 1). The homogenizer Precellys 24 (Berlin Technologies, France) was used to destruct the samples over 40 s at the maximum power (6500 rev/min). The obtained suspension was centrifuged at 16000 rev/min for 5 min, the water phase was separated and subjected to repeated extraction with chloroform. The DNA precipitation was performed by adding equal volumes of isopropyl alcohol. After centrifuging, the precipitate was with 70% ethanol and dissolved in water at 65°C over 5–10 min. The purification of DNA was performed by the method of electrophoresis in 1% agaric gel with further isolation of DNA from the gel by the sorption on silicon oxide [1].

The purified DNA was used as a matrix in the PCR reaction together with a pair of universal primers for the variable site V4 of 16SpPHK-F515 (GTGCCAGC-MGCCGGTAA) and R806 (GGACTACVSGGG-TATCTAAT) [8]. Primers were used with oligonucleotide identifiers for each of the samples and sequences required for pyrosequencing according to the protocol of Roche firm (Switzerland). The sample preparation for sequencing was performed on GS Junior device following the standard recommendations.

About 2000 sequences were obtained for every sample. QIIME allowed processing of the obtained data [9]. The quality, filtration of sequences (nucleotide sequences), combination of sequences into operation taxonomic units (OTU) were tested with the use of 97% similarity level; the OTU taxonomic position – by using the database RDP available on the internet (http://rdp.cme.msu.edu). The taxonomic structure of every microbial community was estimated according to OTU shares referred to different taxones.

Several indices were used to determine the diversity of prokaryotic communities in different soil horizons: the amount of OTUs (S_{obs} – analog of species abundance), Shennon index ($H = \Sigma^{s}_{i=}1p_i \log p_i$, where p_i – a share of species abundance, i) and Chao1 index capable to estimate the actual OTU amount in the community (Chao1 = $S_{obs} + a^2$, where S_{obs} – a number of OTU, a – a number of OTU containing one sequence, b – a number of OTU containing two sequences).

The storage of samples for cultural study was at +4°C. The seeding on nutrient media was in the following composition: KAA: $(NH_4)_2SO_4$ – 2 g, K_2HPO_4 – 1 g, $MgSO_4$ – 1 g, NaCl –1 g, $CaCO_3$ – 3 g, starch – 10 g, agar – 20 g; Chapek medium – KH_2PO_4 – 1 g, $MgSO_4$ – 0.5 g, KCl – 0.5 g, $FeSO_4$ – 0.01 g, $NaNO_3$ – 3 g, glucose or saccharose – 30 g, lactic acid – 4 ml, agar – 20 g; Eshbi medium – KH_2PO_4 – 0.2 g, $MgSO_4$ – 0.2 g, NaCl – 0.2 g, $CaCO_3$ – 3 g, K_2SO_4 – 0.1 g, sugar (mannite) – 10–15 g, agar – 20 g; Vinogradskiy medium – K_2HPO_4 – 0.5 g, $MgSO_4$ – 0.5 g, NaCl, $FeSO_4$, $MnSO_4$. $CaCO_3$ – trace amounts; AMI (agar meat infusion) – meat broth – 1 l, peptone – 10 g, NaCl – 5 g, agar – 2–2.5%, pH = 7.6–7.8. After incubation from 3 to 14 days in dependence on the used nutrient medium the colony-forming units (CFU) were calculated for 1 g of soil.

RESULTS AND DISCUSSION

The analysis of diversity indices showed gradual decreasing the abundant amount of prokaryotic community with the depth (Fig. 1). In the lower part of profile (BC horizon) the species abundance of communities estimated by Chao1 index made up 130 species (OTU). Against the background of gradual decreasing downwards the profile the biodiversity was also sharply declined in the BSNbc horizon (Shennon index was changed from 7.4 to 5.0, the amount of OTU – in the range from 560 to 253 as compared to the BSN horizon). It is known that the solonetz horizons have unfavorable properties for the growth and development of natural vegetation and diversity of its species as well as cultural crops [6]. Having analyzed the data about the diversity indices, it was established that the conditions of the solonetz horizon are also unfavorable for the major part of microbial communities. These data are of interest with account of the fact that the humus content and soil-pH as the main factors affecting the structure of soil microbiome in the BSNbc horizon are almost similar to those in the BSN horizon (Table). Probably, in this case a small diversity of microbiota is connected with the influence of the other factors, for instance, the increased content of exchangeable sodium or the high density in the BSNbc horizon.

The taxonomic structure of prokaryotic microbiomes in different soil horizons at the phylum level is shown in Fig. 2. It is worth empha-

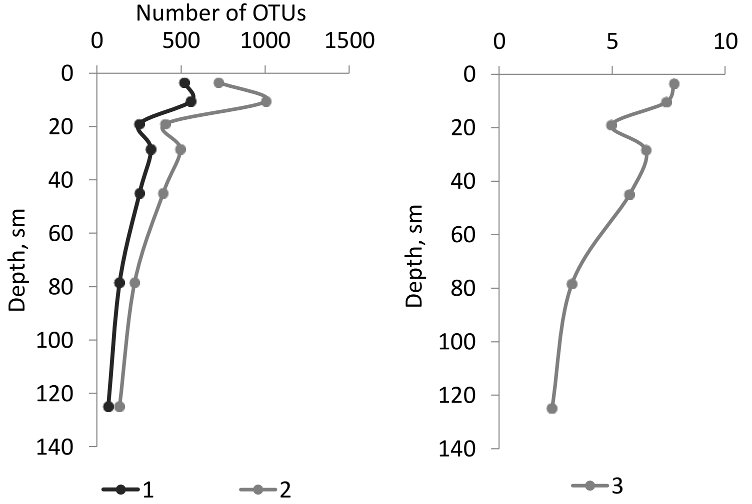

Fig. 1. Values of the biodiversity indices: 1 – the amount of OTU, 2 – Chao1 index (approximate amount of OTU in the community), 3 – Shennon index in genetic horizons within the profile of virgin light-colored solonetz soil.

Results of chemical analysis of virgin light-colored solonetz soil

Depth, cm	pH H_2O	Humus, %	Exchangeable base mmol-equ/100 g					Na^+	Mg^{2+}
			Ca^{2+}	Mg^{2+}	Na^+	K^+	sum	% of the sum	
0–7	7.17	1.51	5.36	2.64	0.69	0.83	9.52	7.25	27.73
7–14	8.11	1.09	4.68	5.36	5.82	0.39	16.25	35.82	32.98
14–24	8.14	1.82	2.48	9.65	10.11	0.52	22.76	44.42	42.40
24–33	8.34	–	1.60	10.42	8.94	0.52	21.48	41.62	48.51
33–57	8.61	–	2.27	6.92	7.09	0.44	16.72	42.40	41.39
57–100	8.86	–	2.60	5.12	6.62	0.35	14.69	45.06	34.85
100–141	8.77	–	2.37	5.82	6.68	0.36	15.23	43.86	38.21
140–160	8.85	–	2.55	6.13	7.07	0.35	16.10	43.91	38.07

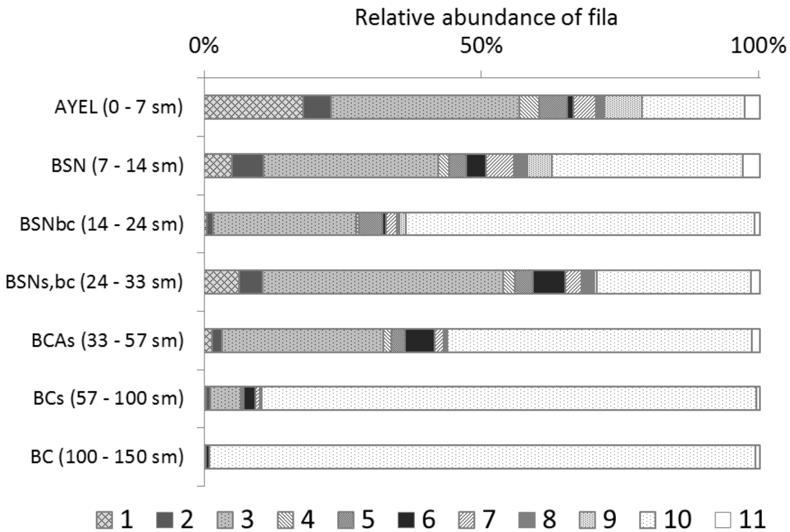

Fig. 2. Taxonomic structure of microbiomes in soil horizons of virgin light-colored solonetz soil, the share of sequences referred to phylumes: 1 – *Thaumarchaeota*, 2 – *Acidobacteria*, 3 – *Actinobacteria*, 4 – *Bacteroidetes*, 5 – *Chloroflexi*, 6 – *Firmicutes*, 7 – *Gemmatimonadetes*, 8 – *Planctomycetes*, 9 – *Verrucomicrobia*, 10 – *Proteobacteria*, 11 – others.

sizing that the major portion of sequences (almost 18% in the topsoil horizon) is regarded to the group of *Thoumararchaeota Archaea*. The representatives of this *Archaea* group are considered as active ammonium oxidizers, which are often present in soil, but they are determined as minor components of the prokaryotic community and don't form a considerable part in the soil microbiome as compared to the solonetz under study.

It was possible to observe the reverse linkage between the biodiversity and portions of *Proteobacteria* representatives – the smaller is the taxonomic diversity of the community, the higher is its share in *Proteobacteria*. In the lower horizon, where the species composition makes up 67 OTU, about 98% of sequences are referred to *Proteobacteria*. Probably, some representatives of this phylum in the given soil are capable to be survived under unfavorable conditions (the low content of organic substances, the increased content of salts), where they seem dominant due to decreasing the population of the other microorganisms. As seen from Fig.3, the share of some prokaryotic species is highly dependent on the depth of genetic horizons. The share of *Candidatus Nitrososphaera (Archaea), Streptomyces, Bacillus* and

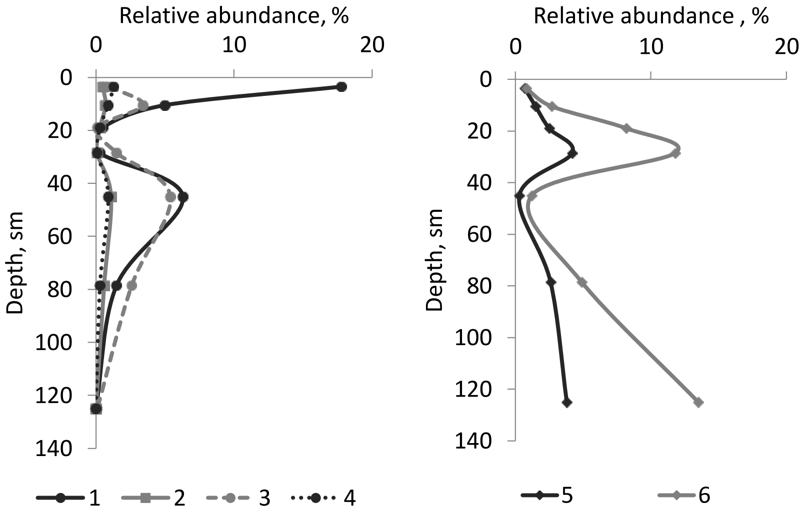

Fig. 3. Distribution of some prokaryotic species along the soil profile: 1 – *Candidatus Nitrososphaera*, 2 – *Streptomyces,* 3 – *Bacillus,* 4 – *Rhodoplanes*, 5 – *Sphingomonas*, 6 – *Pseudomonas.*

Rhodoplanes corresponds to general diversity – the minimum in the BSNbc horizon and in the lower part of the profile. On the contrary, the share of *Springomonas* and *Pseudomonas* as regarded to *Proteobacteria* shows quite the other dependence – the maximum in the BSNbc and BC horizons, whereas their values are minimal in horizons with the increased biodiversity. The population of cultivated groups of microorganisms is shown in Fig. 4. Some ecologic-trophical groups are present only in the topsoil horizons of solonetz soil (about 50%), in the lower horizons they were not found by method of seeding on nutrient media. This is amilolytics and mycelium organisms (fungi and actinomycetes), the functions of which in soil are associated with the destruction of organic polymers that are rather rare in deep soil horizons. It is worthy of note that the results of seeding method revealed no decreasing the population of microorganisms in the solonetz horizon as compared to data of metagenomic analysis. It is evident that the nutrient media cultivate

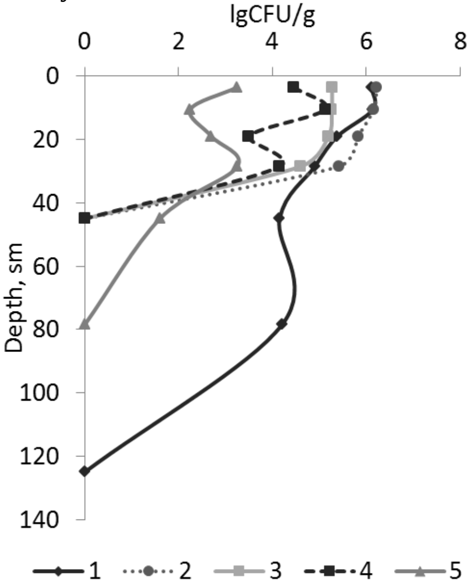

Fig. 4. Population of cultivated microorganisms (lgKOE/g soil) along the profile of virgin light-colored solonetz soil: 1 – ammonifiers, 2 – amilolytic (KAA), 3 – actinomycetes (KAA), 4 – micromycetes (Chapek medium), 5 – anaerobic nitrogen fixers or oligonitrophilous microorganisms (Vinogradskiy medium).

only a small part of soil microbiota but the great amount of rare taxons accounting for a considerable part of microbial diversity cannot be determined with the use of this method. Besides, in horizons with abundant diversity and population of microorganisms KOE can be represented not by cells and spores, they reveal the micro-colonies what additionally decreases their amount.

CONCLUSION

The study of the microbial complex in the complete profile of virgin light-colored solonetz was carried out for the first time by using molecular-biological methods. It was established that the diversity of the prokaryotic complex is gradually changing with depth being sharply declined in the solonetz BSNbc horizon characterizing by the increased density and the high content of exchangeable sodium. There is a reverse linkage between general diversity of the prokaryotic complex and the portion of *Proteobacteria* representatives including *Springomonas* and *Pseudomonas.* In horizons with the lower biodiversity (BSNbc, BCs, BC) these taxons are dominant. In horizons with the higher biodiversity there are representatives from the group of *Thaumarchaeota (Archaea),* the share of which in the topsoil horizon reached 18% of the total prokaryotic complex. The differences in the diversity and structure of microbiome in soil horizons are probably conditioned by the content of the organic matter and the salt composition.

Acknoledgement. This study was financially supported by Russian Foundation of Research, project 15-04-00918.

REFERENCES

1. AndronovE.E., Pinaev A.G., PershinE.V., ChizhevskayaE.P. *Mark-of DNA from soil samples (guidelines)*, St. Petersburg: ARRIAM Agricultural Sciences, 2011, 27 p.
2. *Classification and diagnosis of soil Russia*. Smolensk: Oikumena, 2004, 342 p.
3. LebedevaM.P., KonyushkovaM.V. Temporal Changes in the Microfabrics of Virgin and Reclaimed Solonetzes at the Dzhanybek Research Station,*Eurasian Soil Science,* 2011, Vol. 44, No. 7, pp. 753–765
4. Klassifikatsiya i diagnostikapochvRossii. 2004. Oikumena. 342 p.

5. PershinaE.V., TamazianG.S., DolnikA.S., Pinaev A.G., SergalouN.H., AndronovE.E. Studying the structure of soil microbial community in saline soils by high-throughput pyrosequencing, *Russian J. Genetics: Applied Research*, 2012, T. X, No 2, pp. 31–38.
6. Rode A.A., Polish M.N. Soil Dzhanybek hospital, their seafologicheskoe structure, mechanical and chemical composition and the physical properties, *Proc. Soils. Inst them. V.V.Dokuchaev*, Moscow: AN SSSR, 1961. 56. T. S. 3-214.
7. SapanovM.K. Synchronicity Caspian Sea level change and groundwater in the North Caspian region in the second half of the XX century,*Izvestiya RAS, Ser. Geographic*,2007,No 5,pp. 82-87.
8. Bates S., Berg-Lyons D., CaporasoJ.G., Walters W.A., Knight R., Fierer N. Examining the global distribution of dominant archaeal populations in soil, *ISME J.*, 2011, No 5, pp. 908–917.
9. CaporasoJ.G., Kuczynski J., Stombaugh J. et al. QIIME allows analysis of high throughput community sequencing data, *Nature methods*, 2010, Vol. 7(5), pp. 335–336.
10. *Microbiology of extreme soils*,Eds. Dion P., NautiyalC.S. Berlin/Heidelberg: Springer, 2008, 369 p.
11. World Reference Base for Soil Resources. 2006, FAO, Rome. 128 p.