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STRUCTURAL ORGANIZATION OF ECOSYSTEMS AND PATTERNS OF THEIR DISTRIBUTION

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AGRICULTURAL LANDS IDENTIFICATION ON THE SATELLITE IMAGERY[1]

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Our work aims to determine the possibilities of identification of the fields with various crops, leys and fallows, using the multispectral high resolution (10 m) satellite imageries taken by Sentinel-2 Satellite. For this we studied the irrigation system of Volga-Don in the dry steppe zone of Volgograd Region. We analyzed the images, taken from February to August 2020, and used the field materials, obtained from the surveys that took place from August to September 2020 in the said area. The variations of the agricultural lands structure were carried out visually and automatically, which allowed us to identify winter cereals, spring crops, leys and fallows. Among them we identified such crops as Sudan grass, corn and soybeans. The accuracy of automated method of structure identification was 75%. We used a combination of different channels for multispectral images to divide the irrigated/non-irrigated fields of the irrigation system and the fallows of different years.

This resulted in a creation of a map of agricultural lands structure for the central part of the Volga-Don irrigation system. It shows the cultivated crops on the irrigated and dry lands, leys, uneven-aged fallows and the exact area of each field.

The calculated NDVI values represented the state of crops during different stages of their growing season. The obtained data made it possible to select key sites and study the irrigated soils, because the agricultural crops condition reflected the structure and degradation of the land cover and helps to select the required sites properly.

Our studies have shown us the possibility to use the high resolution remote data for assessment of the structure and state of agricultural lands, and selection of the key sites for soil surveys, the information about which is necessary to develop and select the suitable ameliorative measures.

Keywords: structure of agricultural lands, crops, leys, fallows, irrigated lands, satellite imagery processing.

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In the XX century the large irrigation systems were constructed in the dry steppe zone of European Russia, which made it possible to secure the food supplies for the country even during the dry years. The most active construction took place in the 1950s-1960s; by the middle of the 1980s, the developed areas of the irrigated lands reached their maximum.

However in the 1990s, the large irrigation rates, lack of drainage and water proofing in the most irrigation channels caused a rise of groundwater level, a development of secondary salinization hotbeds, soils alkalization, flooding, irrigational erosion and other negative consequences. The following economic crisis reduced the area of irrigated lands and changed the management of

[1] The study was carried out according to the Governmental Tasks No. 0591-2019-0023 “To Study the Influence of Natural Conditions and Land Use Features on Soil Cover, Including Participation of Saline Solonetzes and Slitized Soils, and to Develop an Assessment Technology for the Intense Soil Exploitation in the Agricultural Lands”. and No. AAAA-A19-119012390065-9 “Development of Methods for Analysis and Complex Use of Earth Remote Sensing Data, Based on the Modern Geoinformation Technologies, for Monitoring of the Natural Landscapes in the Agricultural Lands, Using Groups of Small Spacecraft”.

hydraulic systems. Large areas were abandoned and eventually turned into perennial fallows, some areas were used for dryland farming, and some were irrigated again only after a long period of abandonment or dryland farming, while the other changed their irrigation method. Such drastic transformations of the irrigated lands had affected the state of their soils.

These days the government aims to reconstruct the irrigation systems to restore and improve the management of the ameliorative complex, as well as the amelioration of irrigated lands. To achieve this, it is very important to understand the tendency of soils and soil cover of irrigation systems to transform and evolve over a long period of functioning, and take into account their lithological and geomorphological features, duration of irrigation period and intervals in it. The knowledge, gained from the study of the present state of irrigated soils, will allow us to purposefully select and carry out the necessary agricultural and ameliorative measures to restore the fertility of the soils.

The soil cover of the dry steppe, solonetz zone of the Volgograd Region is heterogeneous, therefore, the surface of agricultural fields is represented on the satellite images by combination of spots, variously sized and colored. These spots are genetically related to the soil structure and affect the crops differently, leading to their sparseness or loss in some cases. To understand the effect of soils and associated spatial heterogeneity of fields on a particular crop, as well as to determine how much the crop condition reflects the condition of soil cover, it is necessary to know the structure of agricultural lands. This allows us to select the key sites for a survey of irrigated soils and take adequate ameliorative measures. The high resolution satellite imagery, being an open and periodic source of information, makes it possible to carry out fast studies in the large areas of irrigated soils.

The aim of this research is to identify the possibilities of recognition of the agricultural lands (fields with different crops, leys and fallow) structure on the high resolution satellite images (10 m), using the visual and automated methods, while taking into account the state of crops and fields, in order to calculate the areas and select the key sites for a further soil survey.

Until 2020 we were studying the agricultural land and irrigated soils in the Volgograd Region, in the area of the Svetloyarsk irrigation system with cultivated fodder grasses, winter cereals and vegetables. I.N. Gorokhova and E.I. Pankova (2017), I. N. Gorokhova et al. (2020) wrote about usage of satellite data to recognize those crops. It was stated that Landsat-8 images (maximum resolution − 15 m) could be used for May or June, because fodder grasses and ripened winter cereals were well-defined on them. However, the Volga-Don system has a wider range of crops, which requires a different approach to the analysis of remote sensing data. For this a series of satellite images taken in different months was used.

The dry steppe zone of Russia undergoes an active agricultural land use. These soils were studied by great Soviet and Russian scientists and by the staff of the V.V. Dokuchaev Soil Science Institute in particular. They recorded the natural state of soils and soil cover in their original condition, before the territory was active developed and irrigated (Ivanova, 1928; Kovda, 1937; Rode, 1947; Antipov-Karatayev, 1953; Bolshakov, 1961).

The irrigated soils have been studied for a long time, in many fields, which results in a creation of many works. These studies are aimed to explore the fluctuations and rise of the groundwater level during irrigation (Minashina, 1978; Zaidelman, 1993), irrigation erosion of irrigated soils (Kuznetsov et al., 1990; Kozlovsky, 1991), secondary salinization processes (Kovda, 1946; Zimovets, 1981; Shahid et al., 2012; Zaman et al., 2018; Ren et al., 2019; Bahmaei et al., 2020), degradation of soil structure at the macro and micro levels (Khitrov et al., 1994; Prikhodko, 1996), alkalization processes (Zimovets, 1981; Zinchenko et al., 2020); carbonization processes (Baranovskaya, Azovtsev, 1981; Lyubimova, Degtyareva, 2000; Lyubimova, Novikova, 2016; Sizemskaya, 2013; Gorokhova, Pankova, 2017), irrigation water effect on soil properties (Bezdnina, 1997; Dedova, 2018; Zinchenko et al., 2020), and movement of soil moisture in irrigated soils (Jiménez-Aguirre et al., 2018).

Aside from a traditional ground sampling, many other methods for assessing the state of irrigated soils are used. Since the 1950s of the XX century, they have been primarily based on the satellite data (Simakova, 1959; Myers et al., 1966; Pankova, Mazikov, 1975; Vyshivkin, 1976; Antonova, Kravtsova, 1976; Richardson, 1976; Sinanuwong et al., 1980; Andronnikov, 1979; Kharitonov, 1982; Manchanda et al., 1983; Myers, 1983; Mamedov, 1985; Pankova, Soloviev, 1993; Hick, Russell, 1990; Singh, 1994; Dwivedi, 1996), and still use it nowadays (Rukhovich, 2009; Konyushkova, 2014; Iqbal, 2011; Abbas et al., 2013; Savin et al., 2014; Pankova et al., 2014, Gorokhova, Pankova, 2017). The majority of articles are written about the saline and solonetz soils.

A large number of the newest literary sources describe the irrigation and its consequences worldwide, while being based on satellite data. The studies of soil salinity were carried out in the Middle East (Allbed et al., 2014), North Africa (Hihi et al., 2019), Turkey (Gorji et al., 2017), China (Jiang, Shu, 2018; Wang et al., 2019; Chi et al., 2019; Ren et al., 2019) and Russia (Komissarov et al., 2019; Gorokhova et al., 2018-2020). The data of Landsat ETM +, Landsat-8 OLI and Sentinel-2 is the most widely used (Jiang et al., 2018; Masoud et al., 2019; Hasanlou, Eftekhari, 2019; Gorokhova et al., 2020).

A group of scientists (Hassania et al., 2020) compiled maps to forecast the distribution of saline and alkaline soils worldwide, using matrix and regression models of the spatiotemporal variability of soil salinity and alkalinity (1980-2018). Similar study was carried out for Hungary (Szatmári et al., 2020).

During the visual decryption of the images, the saline soils can be recognized by white spots, created by a salt crust on their surface. However, this information does not distinguish soil salinity throughout the entire root-inhabited layer, thus limiting the interpretation possibilities. Therefore, during the analysis of multispectral images, salinity is often associated with the state of the crops (Gorokhova et al., 2019). To distinguish different crops, irrigated and non-irrigated fields, to solonetzic, saline and non-saline soils the combinations of various channels of satellite imagery are used, as well as calculated and experiential indices (Allbed et al., 2014; Hihi et al., 2019).

The most used and identified index in the satellite imagery is Normalized Difference Vegetation Index (NDVI), which was first described in 1973 (Rouse et al., 1973). It is a simple index for a qualitative and quantitative assessment of the green mass of vegetation cover. NDVI can be calculated as NDVI=(NIR-RED)/(NIR+RED), where NIR is a brightness or reflectance in the nearest infrared area of the spectrum (0.7-1.0 μm), and RED is in the red area of the spectrum (0.6-0.7 μm). It presumes the ratio of the maximum plants absorption of solar radiation from the red area, and the maximum reflection of the leaf cellular structures in the infrared one.

There are some other vegetation indices, the most well-known of which are SAVI (Huete, 1988), ASVI (Crippen, 1990) and ARVI (Kaufman et al., 1992). They use different channels or corrective coefficients.

However, some researchers do not trust such indexes. A number of authors (Koroleva et al., 2017) believe it is incorrect to use NDVI in determining of the area of the open soil surface, since its accuracy is only 65%. In their opinion, the reliable identification of the area in the spectral space is possible, if the original technology for the spectral vicinity of the soil line, which was developed by them, is used, because its accuracy is 90%. According to this method, the flat part of the tasseled cup, which is considered a soil line (Kauth and Thomas, 1976), is not a synonym with an area of open soil surface, and occupies a significantly smaller area than the area of a soil line.

Nevertheless, vegetation indices are widely used in data services to vegetation monitoring. One of them is VEGA-PRO (2020), which is a satellite service that uses time series of vegetation indices and allows to analyze condition of the vegetation cover (crops and forests), along with its seasonal and long-term dynamics for any point or region of Russia. This system was created by the Russian Space Research Institute of the Russian Academy of Sciences.

Generally speaking, the review of literary sources indicates that there is no strictly defined combination of channels or indices for determining the state of vegetation, crops and soil salinity for different territories. For each specific case an individually selected approach should be developed.

Materials and Methods

Volga-Don irrigation system is located in the dry steppe zone of the Volgograd Region, in the south of the Volga Upland, stretching along the Volga-Don channel, west of Volgograd. We studied its central area, occupied with cultivated fields and fallows. The total area of the study is 8988.9 ha (Fig. 1).

Fig. 1. Volga-Don irrigation system on a satellite image from Google.Earth, 5/11/2020.

The south area, where the irrigation system is located in the Volga Upland, was entirely covered by the Yergeni deposits during the Pliocene Epoch, and then it underwent a gradual denudation. Currently its watersheds are formed with the Yergeni sands, and red-brown Scythian clays and loess loams to the south. The soil-forming rocks are yellow-brown, and their sandy loams are of various depth. The groundwaters are deep and usually slightly mineralized, with a hydrocarbonate-sodium composition. The soil cover is represented by chestnut solonetzic complexes, with dominating loamy chestnut alkaline soils and a small addition of solonetz

(Degtyareva, Zhulidova, 1970; Zinchenko et al., 2020). The variously salinity of alkaline soils and solonetzes affects the state of developing crops.

In this study we used multi-temporal multi-spectral satellite images from Sentinel-2 (Copernicus Open Access Hub, 2020), taken on 2/27/2020, 4/29/2020, 6/28/2020, 7/26/2020 and 8/20/2020, in 4 channels (R, G, B, NIR), with a maximal resolution 10 m; and an image from Landsat-8, taken on 4/04/2020 (Earth Explorer, 2020), in 8 channels, with a maximal resolution 15 m. Additionally, we used the data obtained during the field works in July-August 2020 in the territory of the Volga-Don irrigation system.

During the analysis of the images, a visual and automated decryption of the agricultural lands structure was carried out, using the spectral brightness of the fields with different crops, in 4 channels: 1 − blue (0.4-0.5 μm), 2 − green (0.5-0.6 μm), 3 − red (0.6- 0.7 μm), 4 − near infrared (0.7-0.95 μm). The vegetation indices (NDVI) were calculated, and various combinations of channels and image classification by the values of spectral brightness and NDVI were used.

Results and Discussion

The area that gets sown in the Volgograd Region covers more than 3 million ha, more than half of which is occupied with cereals and grain legumes (Local Agency ..., 2020). Wheat is the most widespread among winter cereals; barley, wheat, oats, corn for grain and ensilage are widespread among spring cereals; peas, chickpeas, sorghum and soybeans − among grain legumes (in limited amounts); mustard, sunflower, safflower, linseed − among industrial crops, and Lucerne with Sudan grass are among forage grasses.

In this region the winter crops of the dry steppe are usually sown in the I-II decade of September and harvested in the II decade of July. The spring crops are sown in different decades of April and harvested in July-August. Ensilage corn and Sudan grass are sown in May and harvested in August. Soybeans are sown from late April to early May and harvested in August (AGRIENE, 2020). According to this distribution, it becomes clear that a series of multi-temporal images should be used in order to identify the land structure in the most reliable way.

In 2020 the following crops were cultivated in the territory of the Volga-Don irrigation system:

1) winter cereals (non-irrigated);
2) spring cereals (non-irrigated)
3) ensilage corn (irrigated);
4) Sudan grass (irrigated and non-irrigated);
5) soybeans (irrigated).

Besides, there were leys and fallow fields.

To recognize the structure of agricultural lands using the satellite images, we had to take into account the following characteristics:

1) the leys on the images are patchy due to the surface erosion and the structure of the soil cover, both of which cause significant fluctuations of spectral brightness within one field;

2) not every field is irrigated, some of them are dry lands, therefore there is a differences in their soil moisture and spectral brightness;

3) some of the fields that are not currently irrigated still have the traces of buried temporary ditches, which affect the overall spectral brightness of the field;

4) the fields may vary in brightness due to agricultural industrial measures that were carried out on them, such as harrowing;

5) 2020 was arid, so the satellite images show its features on them.

Figure 1 shows fragments of images, taken in February, April, June, July and August 2020. The cultivated crops and the general structure of the fields are highlighted. For this we also used the materials obtained during the field studies. The images of such resolution allow us to identify winter cereals and spring crops, leys and fallow. The further separation of spring crops is possible, but with a less probability. Moreover, the small fields and corner areas around the circular fields (0.2-1 ha) can be identified either poorly or not at all.

Further below the visual deciphering of the agricultural lands structure on the multi-temporal images is shown, by the example of the central part of the Volga-Don irrigation system.

Winter crops (1, 1a) are well-distinguished in February, March and April (Fig. 2 A, B, C).

On the April image (Fig. 2 B) it is a perennial fallow (7).

On the June image (Fig. 2 C) these are ripening winter crops (1) and spring cereals (2), Sudan grass (3a), leys (6), fallow (7), but corn (4) and soybeans (5) are not that well distinguished.

On the July image (Fig. 2 D) there are harvested winter crops (1) and spring cereals (2), irrigated growing corn (4) and Sudan grass (3b), leys (6), but the color of non-irrigated Sudan grass (3a), soybeans (5) and fallow (7) barely differ from the leys.

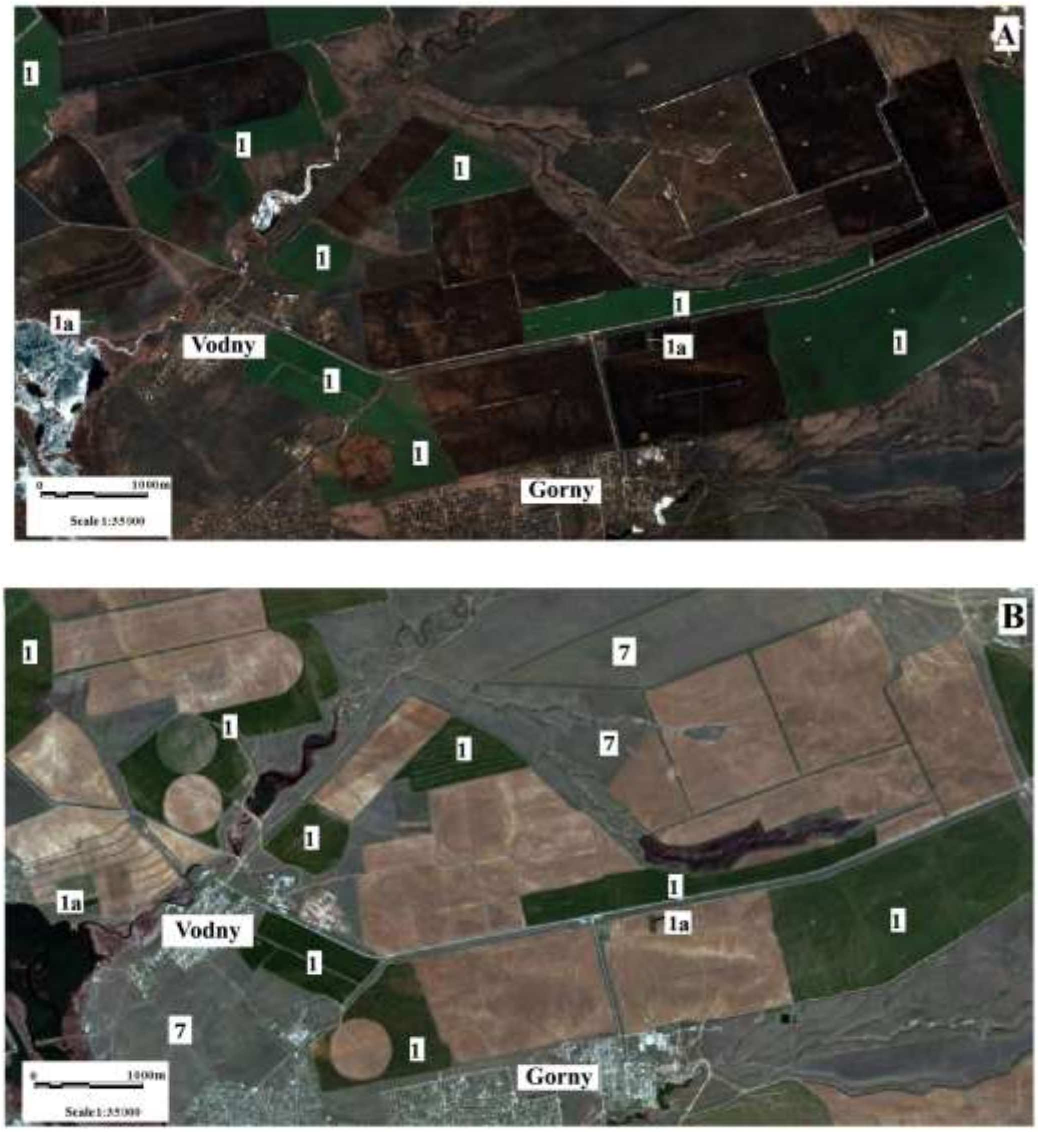


Fig. 2 A, B. Satellite image of the agricultural lands in the central part of the Volga-Don irrigation system (Volgograd Region), taken by Sentinel-2 on A) 2/27/2020, B) 3/28/2020. *Legend:* 1, 1a – winter cereals, 2 – spring cereals, 3a – Sudan grass on the dry lands, 3b – irrigated Sudan grass, 4 – ensilage corn, 5 – soybeans, 6 – leys, 7 – perennial fallow.

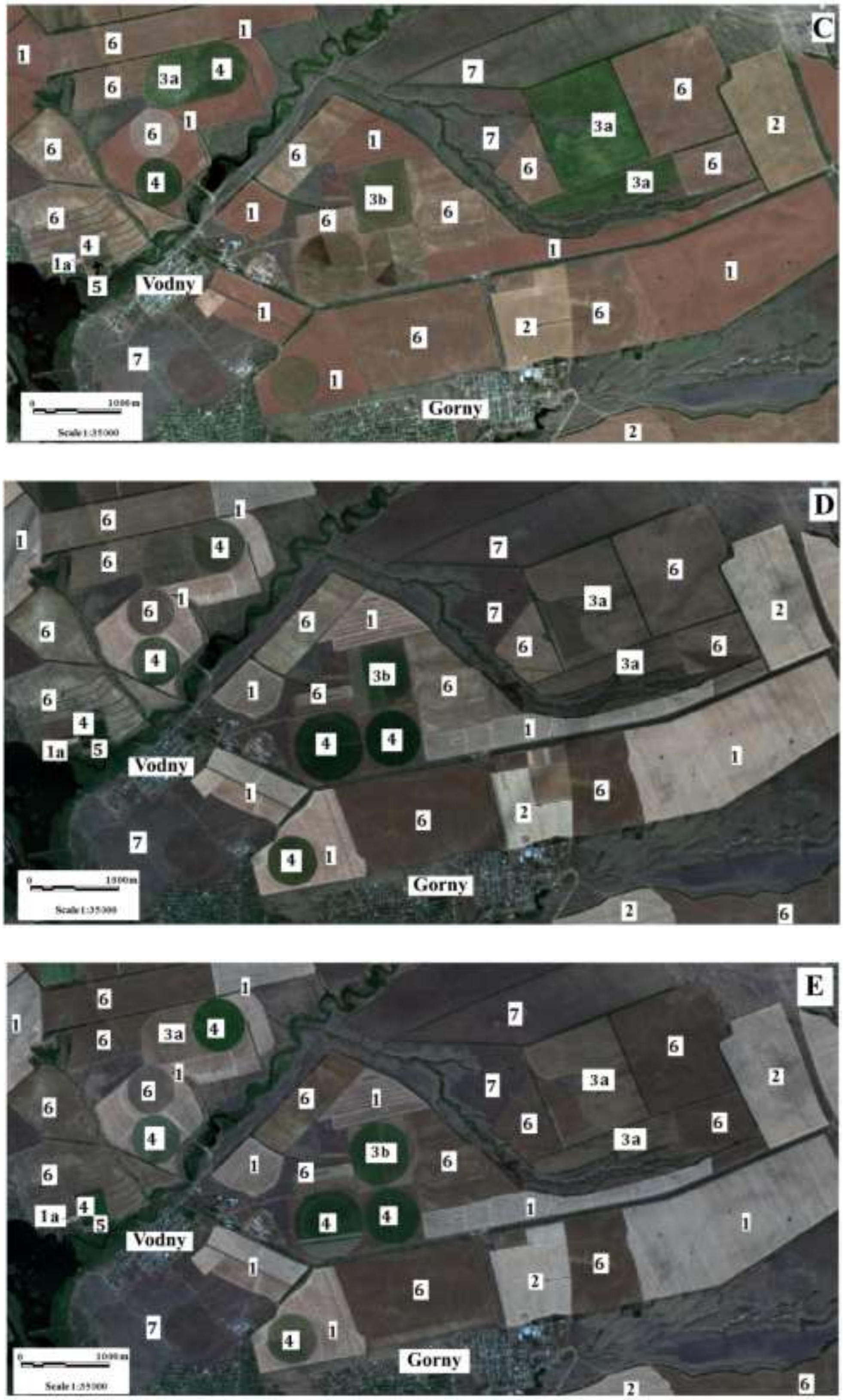


Fig. 2 C, D, E. Satellite image of the agricultural lands in the central part of the Volga-Don irrigation system (Volgograd Region), taken by Sentinel-2 on C) 4/29/2020, D) 5/27/2020, E) 8/20/2020. *Legend:* 1, 1a – winter cereals, 2 – spring cereals, 3a – Sudan grass on the dry lands, 3b – irrigated Sudan grass, 4 – ensilage corn, 5 – soybeans, 6 – leys, 7 – perennial fallow.

On the August image (Fig. 2 E) these are harvested winter crops (1) and spring cereals (2), soybeans (5), irrigated growing corn (4) and Sudan grass (3b), but leys (6) and fallow (7) are almost the same.

Each image does not provide much information about the agricultural lands structure, but, when combined, they give us a full understanding of the situation in this irrigation system.

After this, on the basis of the results of visual recognition, we created the training samples for an algorithm of automated sequential deciphering of the images taken at different times. We used such features as spectral brightness in 4 channels of Sentinel-2 and NDVI. All fields were digitized before we started. The training samples were marked on the images, taken on 2/27/2020, 4/29/2020, 6/28/2020 and 7/26/2020. Then we created an individual sample for each month and built a teaching model on the basis of Random Forest, using Python language. The scheme of the algorithm can be seen in Figure 3.

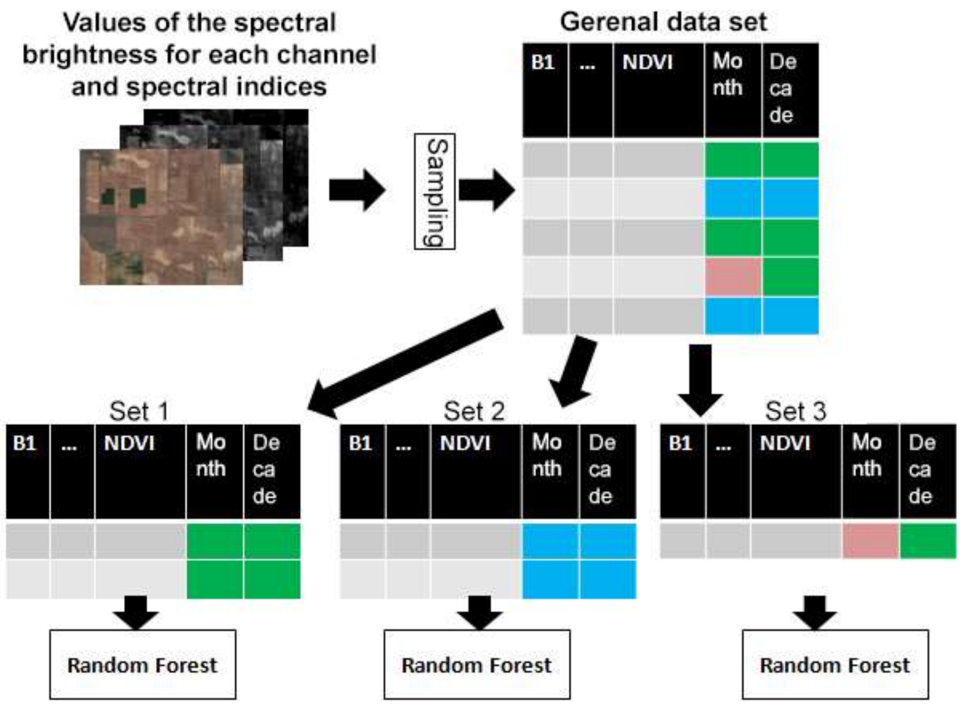


Fig. 3. Algorithm scheme of classification of the satellite imagery with agricultural lands, taken by Sentinel-2.

Random Forest is an ensemble of Decision Tree classifiers or a set of many decision trees. Each sample gets its own decision tree. Unlike an individual classifier, the ensemble tends to overfit less due to the usage of an average forecast for all its trees, resulting in satisfying image classification (Forests of Randomized Trees, 2020).

The results of the automated identification of agricultural lands structure on the satellite images for all dates mentioned above are shown below (Fig. 4).

On the February image (Fig. 4 A) the winter cereals on the big fields are well-distinguished (1), but the small (0.2-0.5 ha) fields (1a) are not. The rest of the fields are an open surface (8).

On the April image (Fig. 4 B) there are also fallows (7) aside from winter cereals (1). The rest of the open surface can be divided into different types by the level of their soil moisture (8, 8a).

On the June image (Fig. 4 C) the ripening winter crops can be identified (1, 1a) and spring cereals (2), non-irrigated Sudan grass (3a), corn (4), soybeans (5), fallow (7) and leys, divided into several types (6, 6a, 6b, 6c).

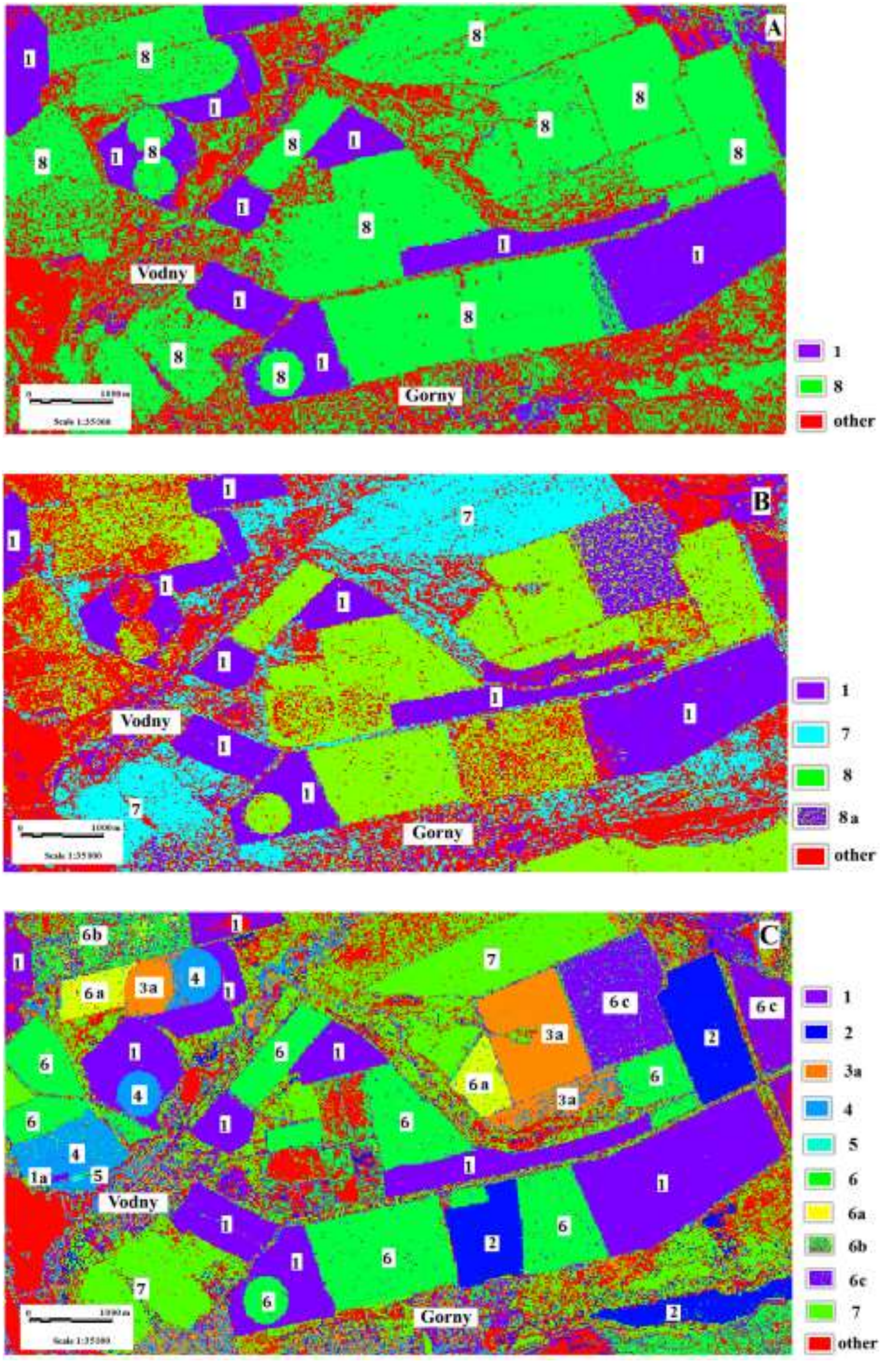


Fig. 4 A, B, C. Results of the automated series classification of the satellite images from Sentinel-2 that was based on Random Forest, and identification of the agricultural lands in the central part of the Volga-Don irrigation system (Volgograd Region) for A) 2/27/2020, B) 3/28/2020, C) 4/29/2020. *Legend:* 1, 1a – winter cereals, 2, 2a – spring cereals, 3a – Sudan grass on a dry land field, 3b – irrigated Sudan grass, 4 – ensilage corn, 6, 6a, 6b, 6c – leys, 7 – perennial fallow, 8 – open field surface.

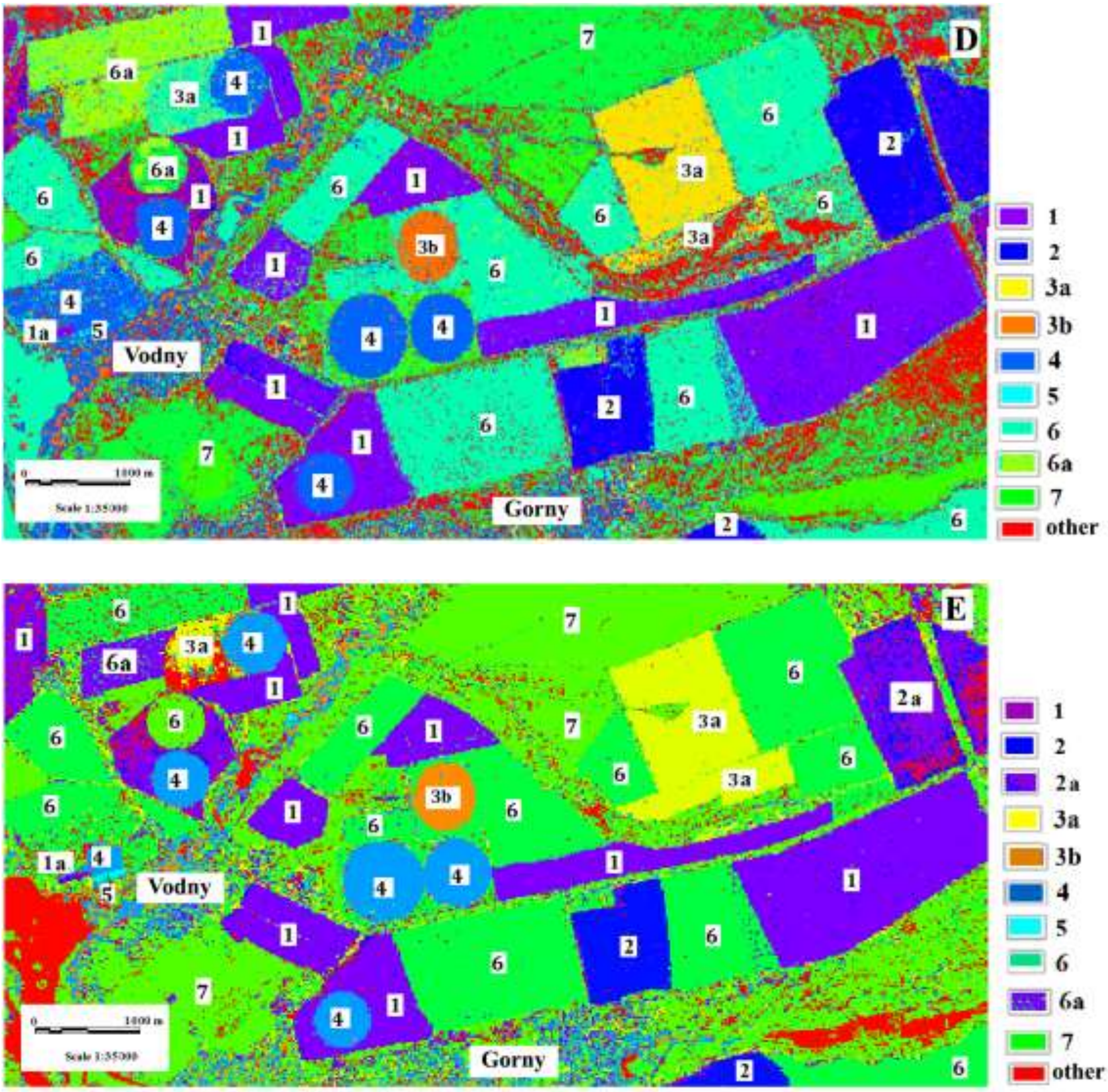


Fig. 4 D, E. Results of the automated series classification of the satellite images from Sentinel-2 that was based on Random Forest, and identification of the agricultural lands in the central part of the Volga-Don irrigation system (Volgograd Region) for D) 5/27/2020, E) 8/20/2020. *Legend:* 1, 1a – winter cereals, 2, 2a – spring cereals, 3a – Sudan grass on a dry land field, 3b – irrigated Sudan grass, 4 – ensilage corn, 6, 6a, 6b, 6c – leys, 7 – perennial fallow, 8 – open field surface.

On the July image (Fig. 4 D) aside from the mentioned crops there is also irrigated Sudan grass (3b), while the leys are divided into two types (6, 6a).

On the August image (Fig. 4 E) there are harvested winter crops (1, 1a) and spring cereals (2), soybeans (5), growing corn (4) and Sudan grass (3b), fallow (7) and leys of two types (6, 6a).

An automated series classification of satellite imagery showed that identification of the agricultural lands structure is possible. However, due to small fields being undistinguished sometimes and ley fields dividing into several classes by the level of their soil moisture, the final stage map compilation requires us to combine those fields separately.

According to the results of this classification, we created a generalized error matrix that can be found in Figure 5. Along its diagonal are the values that indicate the share of correctly classified pixels. Anything that is outside the diagonal is marked as the I and II type errors. The average share of correctly classified pixels for all fields was 75%.

Therefore, with the use of multi-temporal satellite imagery for highlighting of the lands structure, it is possible to classify the image both visually and automatically, with an accuracy of 75%.

When conducting the soil surveys and choosing the key sites for them, it is important to focus on the perennial fallow on previously irrigated lands, which usually the most problematic fields turn into. A special attention is required when studying a young fallow under 5 years old, which could probably form due to the soil degradation.

	1	2	3a	3b	4	5	6	7	10	other
1	0.76497	0.20595	0.03059	0.00485	0.024989	0	0.04363	0.011981	0.051899	0.100128
2	0.07622	0.72569	0.01264	0.00194	0.006181	0	0.01227	0.006879	0.001006	0.018218
3a	0.00054	0.00019	0.76726	0	0.010243	0	1.4E-05	0.000567	4.37E-05	0.001278
3b	1.4E-05	0	0.00063	0.66731	0.024283	0	0.00331	0.001417	2.19E-05	0.002005
4	0.00348	0.00287	0.03249	0.1096	0.79011	0.25	0.01807	0.010356	0.001378	0.016272
5	0	0	0.00025	0	0.006181	0.73684	4.2E-05	5.67E-05	0	0.000494
6	0.03194	0.02266	0.10013	0.1581	0.063929	0	0.81623	0.028629	0.025217	0.068253
7	0.00387	0.00418	0.02099	0.0291	0.030022	0	0.01614	0.78119	0.00573	0.166173
10	0.01258	0.00117	0.0019	0.00097	0.012539	0	0.03491	0.012604	0.763051	0.101203
other	0.10637	0.03729	0.03312	0.02813	0.031523	0.01316	0.05539	0.146321	0.151652	0.525976

Fig. 5. Generalized error matrix.

There is also a large number of non-irrigated fields in the territory of the Volga-Don irrigation system, which may be a sign of cost savings for irrigation, as well as the patchy and complex soil cover, a significant amount of saline and solonetzic soils that force the farms to leave these fields without any irrigation.

To separate irrigated and non-irrigated fields, to identify and divide the fallows under and over 5 years old, we select empirically and use a combination of different channels for the multispectral satellite images (Fig. 6, 7).

When identifying a perennial fallow on the image taken by Landsat-8 on 4/04/2020, using a combination of channels 7, 5 and 4 (short-wave infrared, near infrared, red), a younger deposit (under 5 years old) is highlighted with saturated pink, while an older one is highlighted with pale pink (Fig. 6 A). The reliability of this identification can be proved by comparing the new image with the older one, taken 5 years ago and shown below (Fig. 6 B).

The irrigated areas are marked with violet on a satellite image from Sentinel-2, taken on 7/27/2020, in a combination of the channels 2, 3 and 4 (green, red, near infrared; Fig. 7).

Based on the final results, we created a map of the agricultural lands structure for the central part of the Volga-Don irrigation system. It shows the fields with different crops, whether they are irrigated or not, as well as it shows the leys, uneven-aged fallow and the areas of all fields (Fig. 8).

We determined that 35% of the total area of the studied agricultural fields (8988.9 ha) was cultivated, 36.8% was left under the leys, and 28.6% turned into a fallow, which is a significant share. But only 3.5% of the cultivated fields were irrigated, which is unacceptably low. The reason for poor lands development can be economic problems, as well as degraded and complex soil cover.

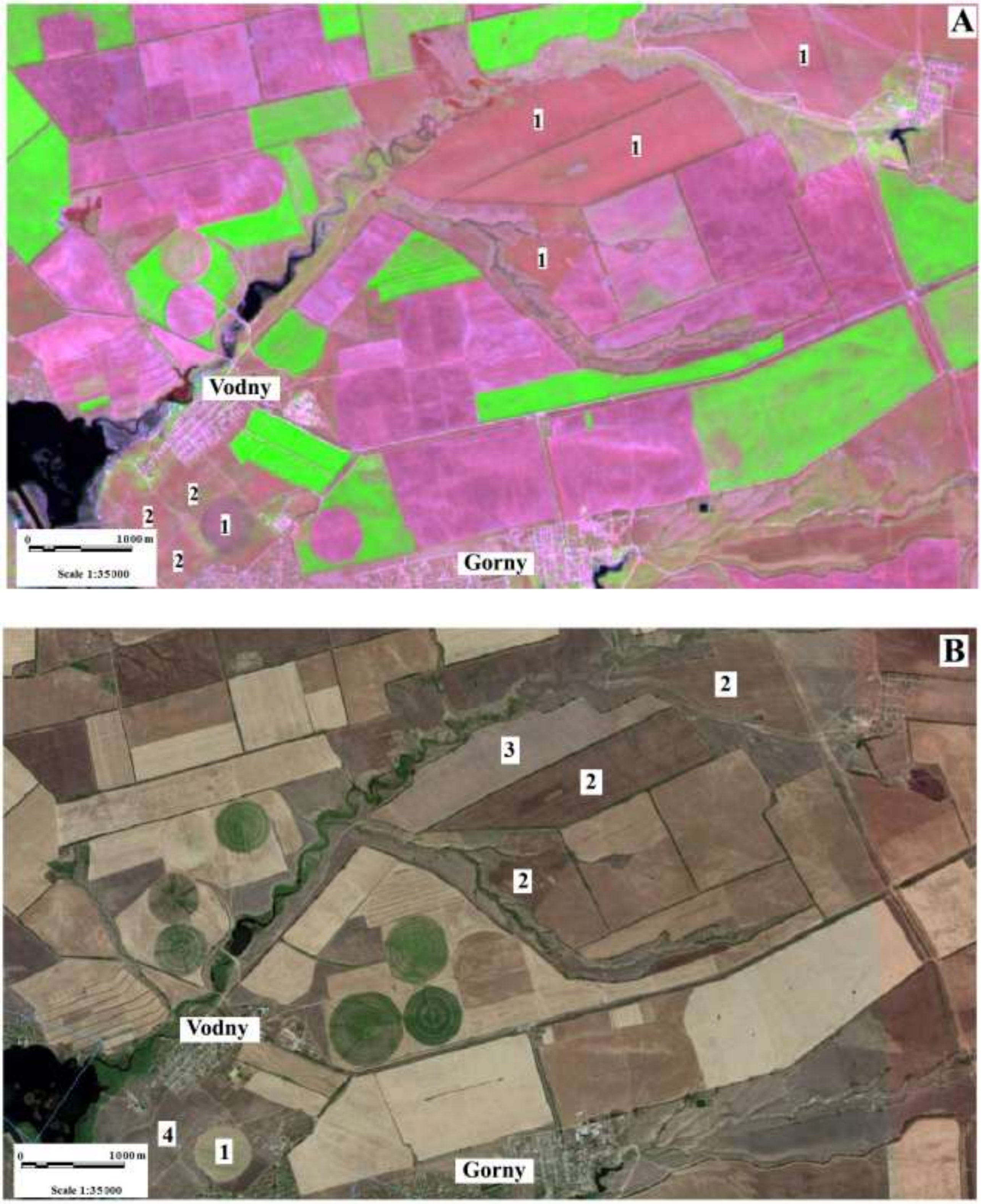


Fig. 6. A) perennial fallow on the satellite image taken on 4/04/2020 by Landsat-8, in a combination of channels 7, 5 and 4 (short-wave infrared, near infrared, red); B) fields on the satellite image from Google.Earth, taken on 8/05/2015, than turned into a perennial fallow by 2020. *Legend.* A) 1 – fallow under 5 years old, 2 – fallow over 5 years old; B) 1 – harvested field, 2 – arable land, 3 – ley field, 4 – perennial fallow.

Fig. 7. Violet (1) marks the irrigated areas on the image taken on 7/27/2020 by Sentinel-2, in a combination of the channels 2, 3 and 4 (green, red, near infrared).

The total area of 130 fields was 8988.9 ha. The winter cereals occupied 2026.2 ha (22.5%), spring crops – 493.0 ha (5.5%), irrigated Sudan grass − 44.2 ha (0.5 %), non-irrigated – 300.5 ha (3.3%), irrigated ensilage corn – 255.0 ha (2.8%), irrigated soybeans – 3.4 ha (0.05%), leys – 3304.3 ha (36.8%), fallow under 5 years old – 1205.8 ha (13.4%), over 5 years old – 1356.5 ha (15.1%).

This means that 35% of the total fields were cultivated, 36.8% were left under the leys, and 28.6% became a fallow, which is a significant amount. But only 3.5% of the cultivated fields were irrigated, which is unacceptably low. The reason for this could be economic problem of the farms and degraded, complex soil cover that requires an expensive amelioration.

We assessed the cultivated crops condition, using NDVI (Table 1).

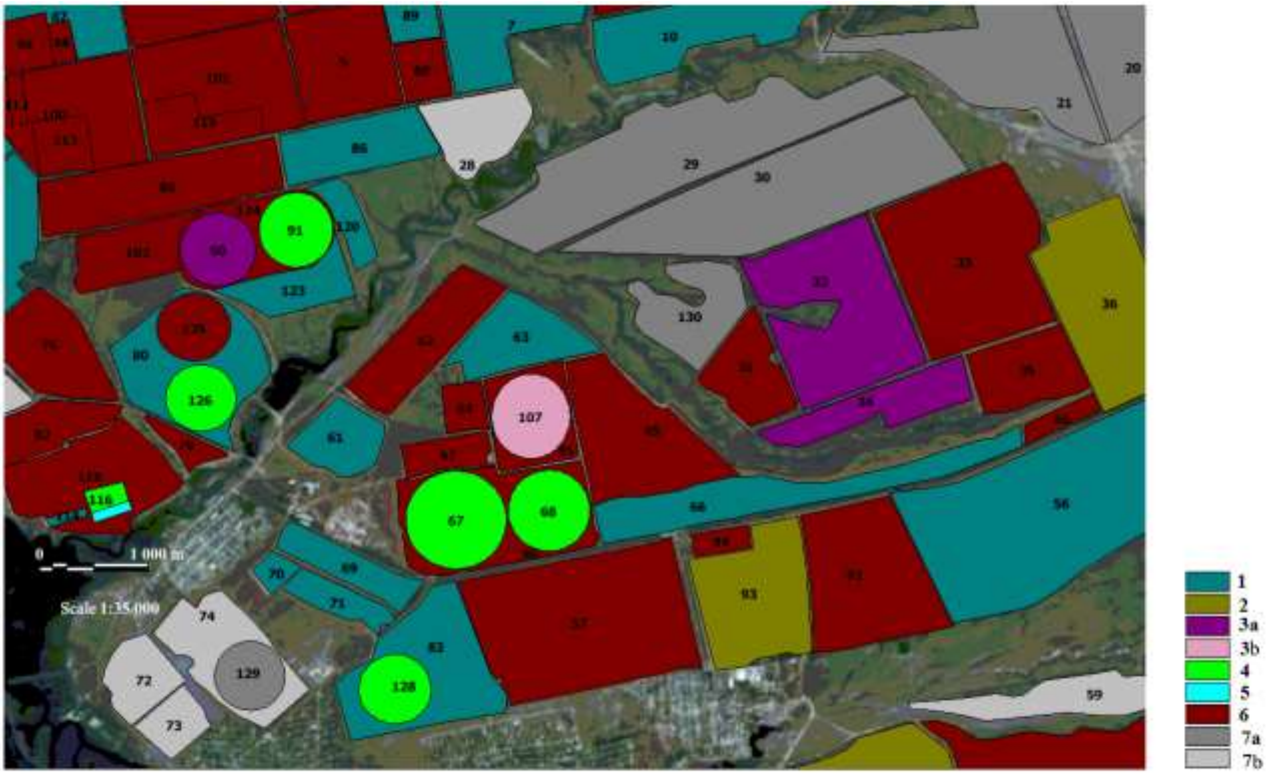
When the vegetation cover is sparse, the spectrum depends mostly on soil, and soils background affects NDVI severely. Due to the crops diversity, patchiness of the soil cover and dry weather of 2020, the NDVI values range significantly between different types of crops in the territory of the Volga-Don irrigation system.

The NDVI values are quite even (0.13-0.17) for the ley fields during the entire period of our study, which matches the values of the open soil surface.

Winter cereals reach their highest index NDVI in April (0.72-0.73), ripe by June (0.2-0.21) and are harvested in July. The index for corn, soybeans and irrigated Sudan grass is at its maximum in August (0.60-0.88), when the harvest begins. The NDVI values for fallow are in-between leys and growing crops (0.20-0.40) due to the weeds, the index of which reaches its highest in June (0.38-0.48), but never exceeds 0.5.

The spring cereals were noted to have a special way of development. We analyzed them on the images separately, because the time intervals, suggested in Table 1, could not cover their short growing season. The cereals were growing most actively in the end of May, and reached maturity at the beginning of July and were harvested. The maximum NDVI (0.52-0.54) indicated they were not growing sufficiently enough, which could be due to the dry year, and, perhaps, it was the exact reason for an early harvest (Table 2).

If the range of NDVI values on a field with only one type of crop on the active stage of growing differs by 0.1 and more (Sudan grass on dry land, soybeans), it is a sign of its uneven development, which can be due to the patchy soil cover and, therefore, requires a special treatment when the key sites are selected.



No.	Code	Subject	Area, ha
29	7	Fallow under 5 years	229,7
30	7	Fallow under 5 years	233,4
31	6	Leys	52,3
32	3	Sudan grass on dry land	167,3
33	6	Leys	193,5
34	3	Sudan grass on dry land	59,2
35	6	Leys	59,8
36	2	Spring cereals	161,6
37	1	Winter cereals	128,2
38	7	Fallow under 5 years	87,8
39	6	Leys	172,5
40	7	Fallow under 5 years	41,4
41	7	Fallow over 5 years	7,7
42	7	Fallow over 5 years	12,7
43	7	Fallow over 5 years	17,1
44	7	Fallow over 5 years	17,1
45	7	Fallow over 5 years	16,4
46	7	Fallow over 5 years	25,1
47	7	Fallow over 5 years	27,8
48	7	Fallow over 5 years	17,5

No.	Code	Subject	Area, ha
49	7	Fallow over 5 years	19,8
50	7	Fallow over 5 years	14,5
51	1	Winter cereals	111,1
52	1	Winter cereals	19,1
53	7	Fallow over 5 years	123,3
54	1	Winter cereals	140,5
55	7	Fallow over 5 years	247,8
56	1	Winter cereals	337,4
57	6	Leys	230,8
58	7	Fallow over 5 years	86,7
59	7	Fallow over 5 years	89,5
60	6	Leys	12,5
61	1	Winter cereals	40,8
62	6	Leys	74,2
63	1	Winter cereals	60,0
64	6	Leys	16,5
65	6	Leys	117,2
66	1	Winter cereals	105,4
67	4	Irrigated ensilage corn	65,6
68	4	Irrigated ensilage corn	44,2

Fig. 8. Structure of the agricultural lands in the central part of the Volga-Don irrigation system (Volgograd Region) in 2020 and the area of each field. *Notes:* 1 – winter cereals, 2 – spring cereals, 3a – Sudan grass on dry lands, 3b – irrigated Sudan grass, 4 – irrigated ensilage corn, 5 – irrigated soybeans, 6 – leys, 7a – fallow under 5 years old, 7б – fallow over 5 years old, 63-74 – field number.

To make a general representation of the way the NDVI values distributed over the territory of the central part of the Volga-Don system, we classified the satellite image from Sentinel-2, taken in July (Fig. 9). It can be seen on the Figure 9 that there are fields with harvested crops and leys at NDVI≤0.2, fields with fallow and Sudan grass on dry land at 0.2-0.4, and fields with variously growing irrigated crops (corn, soybeans, Sudan grass) at 0.4-1, as well as garden plots in the villages and heavily vegetating plants in the gullies.

Therefore, the analysis of the NDVI values makes it possible to separate the growing crops, leys and fallow, to determine the state of the crop and use its uneven development to determine the areas with the highest patchiness of the soil cover.

Table 1. NDVI values for the agricultural lands of the Volga-Don irrigation system in February-August 2020.

No.	crop type	February	April	June	July	August
1	winter cereals	0.62-0.70	0.72-0.73	0.20-0.21	harvested	harvested
3a	Sudan grass on the dry land			0.64-0.76	0.28-0.30	0.26-0.28
3b	irrigated Sudan grass			0.60-0.66	0.60-0.80	0.60-0.85
4	ensilage corn			0.69-0.71	0.83-0.86	0.80-0.85
5	soybeans			0.37-0.47	0.47-0.50	0.79-0.88
6	leys	0.15-0.17	0.14-0.19	0.16-0.18	0.14-0.15	0.13-0.15
7	fallow		0.34-0.40	0.38-0.48	0.24-0.31	0.20-0.21

Table 2. NDVI values for the spring cereals in the territory of the Volga-Don irrigation system in May-August 2020.

No.	crop type	May	June	early July	late July	August
2	spring cereals	0.52-0.54	0.23-0.25	0.14-0.15	harvested	harvested

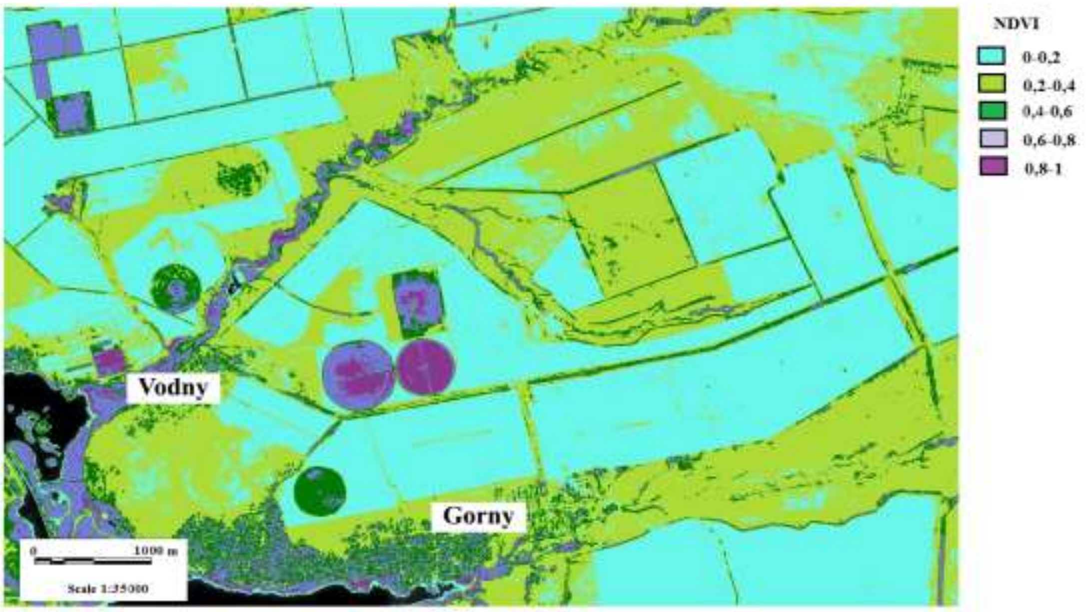


Fig. 9. Classification by the NDVI values of the satellite image from Sentinel-2, taken on 7/27/2020 in the central part of the Volga-Don irrigation system.

Then, based on the obtained results, we selected several key sites for further study of irrigated soils (Fig. 10). The first site was a field with Sudan grass on dry soils, with NDVI less than 0.4 during the active phase of the growing season, which was a sign of soil degradation that were reducing the vegetation activity of the crop (most likely, it was alkaline soil). The second one was selected due to its patchy ley field, which indicated the erosional soil degradation. The third one was on a field with buried temporary ditches, which implied a strong anthropogenic impact on soils and a diversity of soil formations. The fourth one was with a fallow over 5 years old, which indicated a complex soil cover and made it necessary to leave the field without cultivation and irrigation for a long period of time. The fifth one was an irrigated field with a successfully growing crop (silage corn), where the NDVI was more than 0.8.

Fig. 10. Selected key sites (1-5) for a soil survey, marked on a satellite image from Sentinel-2, 8/27/2020.

Conclusions

This study aimed to identify the possibility to recognize the structure of agricultural lands (fields with various crops, leys and fallows), using the multispectral high resolution satellite imagery (10 m) from Sentinel-2. It took place in the area of Volga-Don irrigation system that was located in the dry steppe solonetz zone of Volgograd Region. The idea was to select some key areas for soil survey afterwards, while taking into account the state of crops and fields. For this we analyzed the images, taken in the said area in February-August 2020, and used materials from field surveys that were carried out in August-September 2020. The structure recognition was made visually and automatically.

In the process we discovered that after a sequential visual analysis of multi-temporal multispectral satellite images was carried out, the winter crops stood out the most in February, March and April. On the April image it was the perennial fallow that was well defined; in June it was the ripening winter and spring crops, Sudan grass on dry land, leys and fallow, but irrigated corn and soybeans were barely recognizable; in July the harvested winter and spring crops, corn and leys were clearly visible, but the color of Sudan grass on dry land, soybeans and fallow hardly differed from the leys; in August the harvested winter and spring crops, soybeans and corn were well-defined, but leys and fallow did not differ too much. The satellite images that had been taken at different times, made it possible for us to mark all cultivated fields on the irrigation system.

We used a Random Forest method, based on an ensemble of Decision Tree classifiers, to automatically classify satellite imagery and highlight the structure of agricultural lands. In this method we used training samples that were based on visual interpretation of images, as well as took into account such features as spectral brightness in 4 channels of Sentinel-2, and NDVI values. The images that were processed had been taken in February-August 2020. According to the results, the structure was the clearest for June and July. We found out that small fields (with an area of 0.2-0.5 ha) could not be identified separately, because the merged with the surrounding background; while the ley fields could divide into 2 or 3 classes, depending on the month when the image was taken (and the difference in soil moisture), and therefore we had to combine them at the final stage of the processing.

The results helped us to comply a generalized error matrix, which showed that the average share of correctly classified pixels was 75% for the analyzed agricultural lands, therefore, this method of image processing can be considered acceptable.

The combination of different channels allowed us to separate the irrigated and non-irrigated fields on the irrigation system from the fallows of different ages.

After the work was finished, we created a map of the agricultural lands structure for the central part of the Volga-Don irrigation system. It shows the fields with different crops, whether they are irrigated or not, as well as it shows the leys, uneven-aged fallow and the areas of all fields.

We determined that 35% of the total area of the studied agricultural fields (8988.9 ha) was cultivated, 36.8% was left under the leys, and 28.6% turned into a fallow, which is a significant share. But only 3.5% of the cultivated fields were irrigated, which is unacceptably low. The reason for poor lands development can be economic problem, as well as degraded and complex soil cover.

We calculated the NDVI values to reflect the crops state at the different stages of their growth. The analyzed material made it possible to select key sites for the further soil survey, since the state of crops, among many other factors, reflects the structure and degradation of soil cover, and helps to select correctly the said sites to study and develop the required ameliorative measures for irrigated soils fertility improvement in the future.

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