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RESEARCH ARTICLE

The state of agrocenosises and hayfield meadows in farm units of Prialeisk soil and climate zone (Altai Krai)

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Abstract

This paper presents the results of the estimation of agrocenoses and hayfield meadows of Prialeisk soil and climate zone in Altai krai. For the period 2001-2021 there is a pronounced trend for increasing yields in almost all crops. The exception includes only permanent grasses for green feed which is explained by aridization of the climate and the established agrotechnology in recent decades. Data analysis shows that planting acreages have decreased for such crops as spring wheat (from 107.3 thousand ha in 2001 to 59.7 thousand ha in 2021), oat (from 8.6 thousand ha in 2001 to 6.2 thousand ha in 2021) and permanent grasses (from 15.4 thousand ha in 2001 to 4.8 thousand ha in 2021). When estimating the monitoring areas with agrocenoses on the water index calculated using Sentinel-2 data it was identified that for sainfoin, linen, sunflower, lucerne and corn the range of NDWI values ranged from -0.2 to 0.4. Whereas they were drought tolerant crops, stress was insignificant. Hayland haylages as forage lands did not have any negative index values. For oat and soy, the index indicators were lower, the values ranged from -0.2 to 0.25. A value range for wheat varied from -0.2 to 0.3. Buckwheat was rich in phytomass and the NDWI value range was from -0.1 to 0.45. That gave evidence of the sufficient water availability of the crop. Agrocenoses productivity depended on the level of the area moistening and the soil and climate conditions were fairly homogeneous on the selected territories as correlation between ARVI and NDWI values was 0.9. According to the satellite data the most productive ones were oat crops with sainfoin and buckwheat.

Keywords
Agrocenoses, hayland, haylages, Altai krai, vegetation index, biologization of agriculture

Introduction

Recognition of spatial and temporal variability of environmental factors that directly impact the productivity of agroecosystems is necessary for solving the most important agriculture problems: sustainable growth of production, self-sufficiency, low-cost, resource saving and environmental protection. The above problems are root causes for the ecological crisis and not only a domestic one but also for the world agricultural production, that requires a change in the agriculture methodology (Tovkach and Shutov 2008; Kudriashova et al. 2014; Lekomtsev 2015).

The theoretical concepts of the biological approach to agriculture have long been laid down in science. Though their realization within the framework of such a farming program is due to many factors including weather conditions, technology level of development and styles of crop rotations. The transition to biologized agriculture is directed at the insertion and adaptation of energy saving technologies. Technologies of accurate planting, fertilization and harvesting refer to the technical processes that are used in biologize agriculture. The methods of landscape specific agriculture and high-precision methods (precision agriculture) are the most important in this concept.

Precision agriculture can be defined as a set of technological methods that provide differential treatment of separate parts of the field considering its inhomogeneity crop-producing power and the spread of parasites, diseases and weeds with a reasonable dosage of impact with a view to creating the basis for economically efficient and environmentally sound land management (Shpaar et al. 2008). The development of precision agriculture has become possible because of the appearance of remote sensing, soft and hardware, a global positioning system and a Geological Information System (GIS) as well as agrarian machineries capable of differential treatment of the field (Domsh 2001; Lachuga 2005). As practice shows, the introduction of this technology promises revolutionary transformations in agriculture as it significantly increases production efficiency improving productivity, profitability, product quality, environmental protection which ultimately raises not only the culture of production, but also contributes to the development of rural areas as a whole (quoted by Lekomtsev 2015).

The goal of research: estimation of the state of croplands and hayfield meadows of agricultural holdings in Aleisk region with the help of ground- and satellite-based agromonitoring methods.

The object of research: the agrocenoses of wheat, oat, sunflower, buckwheat, soy, sainfoin, linen and corn. The subject of the research: yield, water availability and contamination of agrocenoses.

Material and methods

The researched agrocenoses and hayfield meadows were situated within the boundaries of the Prialeisk soil and climate zone (Khalin et al. 2018). The work was carried out on agriculturally used areas of studied agricultural holdings located in Aleisk administrative region. The main monitoring areas were located on the territory of the agricultural holding of LLC "Zolotaia osen".

Aleisk region is located in a continental climate in the central part of Altai krai. The region terrain is a young plain dissected by rivers and ravines. The average January temperature is −17.6 °C and the average July temperature is +20 °C. Precipitation falls 320-470 mm per year (Fig. 1).

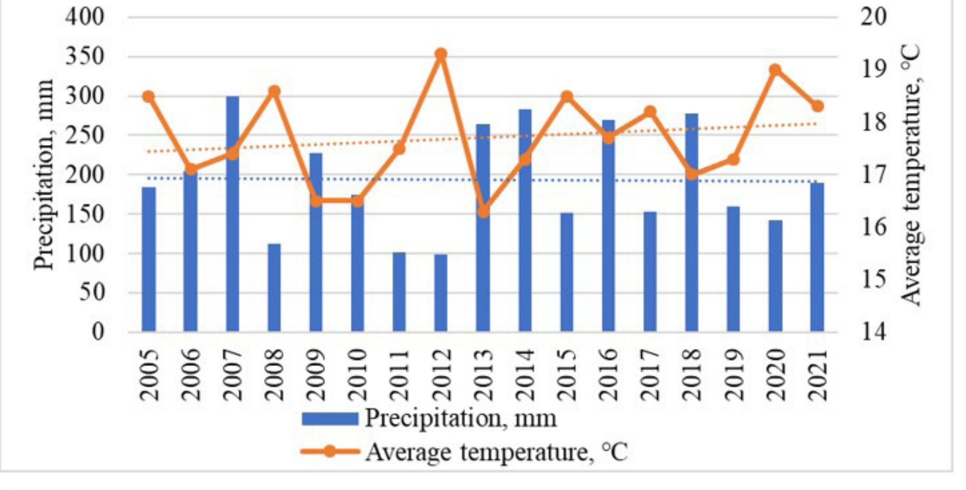


Figure 1. Dynamics of weather conditions of the vegetational season (May-August) 2005-2021 according to the meteorologic station of Aleisk (https://rp5.ru/).

Weather conditions of the vegetational season 2005-2021 showed their extreme inhomogeneity. The average temperature of the period from May to August was +17.7 °C, the average precipitation was at the level of 193.4 mm. The humidity factor, being in the range of 0.6-0.8, increased in moisty years to 1.0-1.2. The length of the vegetational season was 123-127 days (https://rp5.ru/). The soil landscape is mainly typical and leached chernozems. Solonetzic chernozems are common for the southwestern part of the zone. According to the granulometric composition all soils are argillaceous. The humus content is 3-6%, the base exchange capacity is equal to 40-50 mg-eq per 100 g of soil. The content of total phosphorus reaches 0.13-0.16%, labile phosphorus – 200-250, exchangeable potassium 300-350 mg/kg. The desired content of labile phosphorus is 250 and exchangeable potassium is 250 mg/kg (Khalin et al. 2018, 2020).

During the work route methods were used in the process of which geobotanical descriptions, mapping of work points and herborization were carried out. Geobotanical researches of agrocenoses and hayfield meadows were performed on test areas by the method of semi-stationary areas combined with the route method for sown crops (wheat, oat, sunflower, buckwheat, soy, sainfoin, linen and corn) (Yunnatov 1964; Greig-Smith 1984; Rysin 2007). GPS coordinates with an accuracy of up to 3 m were recorded for each area.

11 Sentinel-2 satellite photos for 2022 (1 pixel = 10x10 m) were used for the work. NDWI 2 maps were compiled for separate dates – 12.05.2022 (water availability) and 21.08.2022 (water stress). The K-means automated learning methodology and a decision tree were used for mapping. The open source SNAP software from ESA was used to process the photos.

The analysis of the seasonal dynamics of agrocenoses and the estimation of their productivity were based on the calculation of the spectral indexes. Data processing included the following stages:

1. Calculation of vegetation index (ARVI and NDWI) on the research territory for the vegetational period of 2022 (Cherepanov 2011; Kravtsov 2010);
2. Creation of cloud masks for individual photos in 2022 was carried out by constructing of a method of unsupervised classification of K-Means method for channels1,8 and 8A with binary classes, then a vector layer was separated. Cloud masks were designed on its basis;
3. Creation of maps of productivity of ARVI (atmosphere resistant vegetation index) and water content of NDWI (moisture content index) according to the decision tree method on the basis of the preliminary breakdown of classes with the K-Means method;
4. Construction of vector contours of field (50 contours);
5. Data analysis for the researched objects including regression analysis, vegetational curves integration and comparison with the ground-based data. Data processing was made with Microsoft Excel program.

The received maps of vegetation indexes allow to identify problem growth areas and give an opportunity to make the most suitable long-term decisions directed at the crop productivity raising. The estimation of the growing conditions of the types of the crop species in the Prialeisk soil and climate zone was made on the basis of the ground- and satellite-based monitoring data.

Results

The analysis of the growing areas and the crop yields in Aleisk region in Altai krai for the 20 years period is shown in figures 2-7.

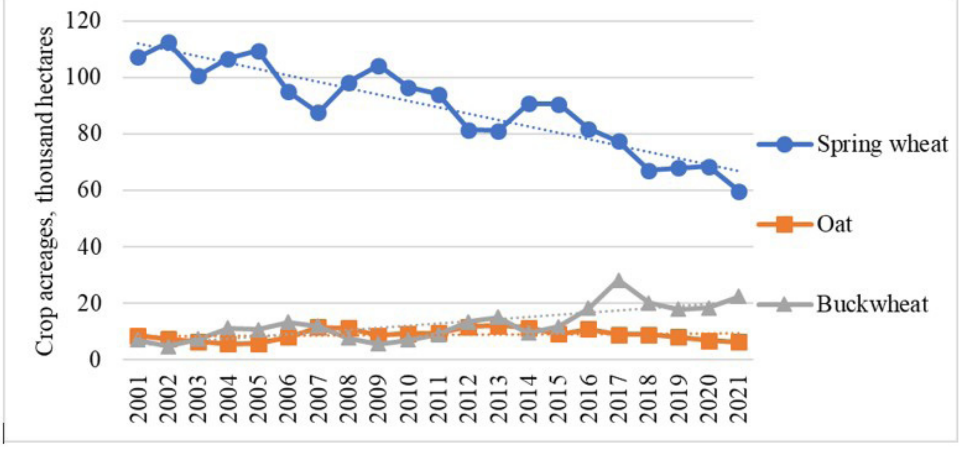


Figure 2. Crop acreages of spring wheat, oat and buckwheat.

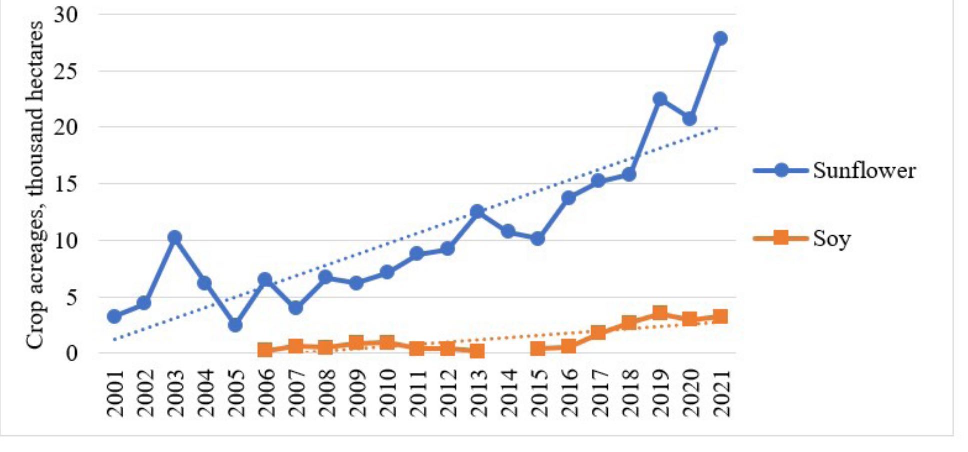
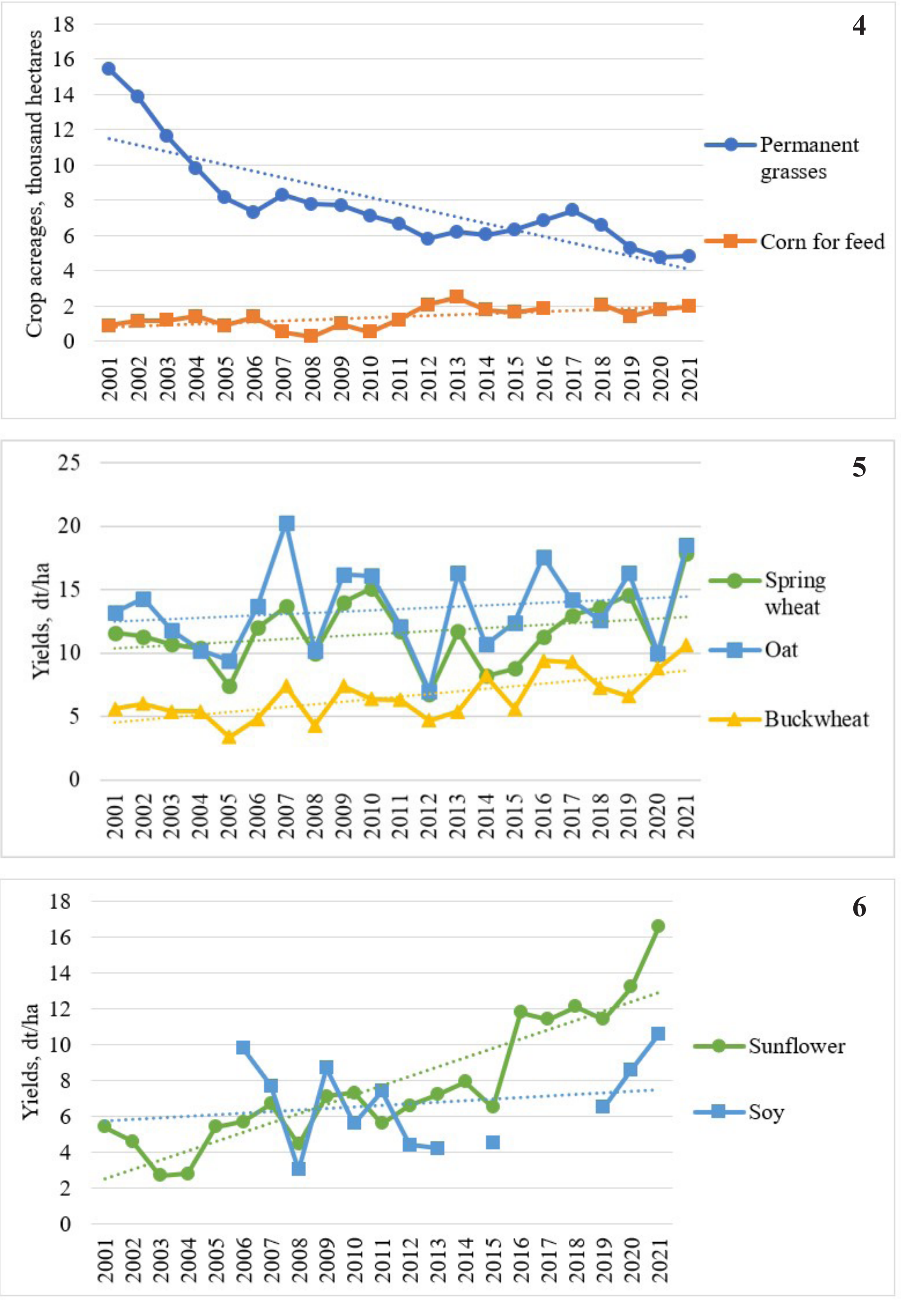


Figure 3. Crop acreages of sunflower and soy.



Figures 4–6. **4** – Crop acreages of permanent grasses and corn for feed; **5** – Yields of spring wheat, oat and buckwheat; **6** – Yields of sunflower and soy.

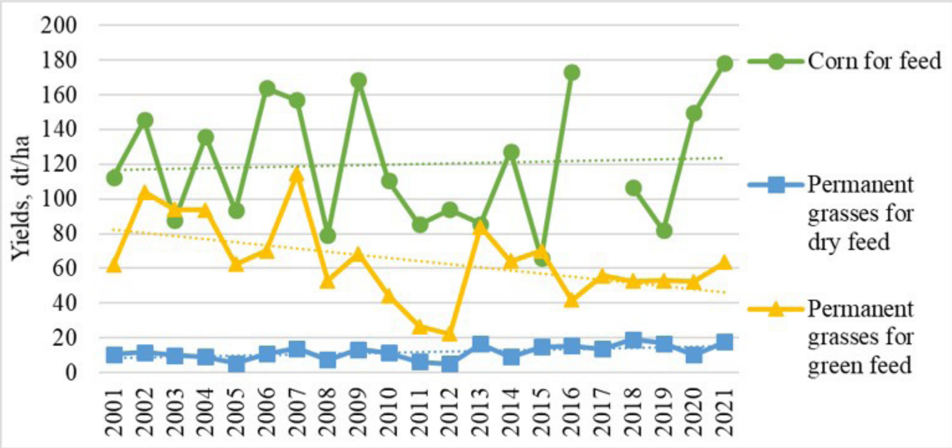


Figure 7. Yields of permanent grasses and corn for feed.

For the period 2001-2021 almost all cultures showed a pronounced trend for the crop productivity increasing (Figs 5-7). The only exception was permanent grasses for green feed but it can be explained by the climate aridization and agrotechnologies of the recent decades. The crop acreage under spring wheat and permanent grasses decreased for the 20 years period respectively from 107.3 to 59.7 thousand hectares and from 15.4 to 4.8 thousand hectares. The sunflower acreages increased significantly from 3.3 thousand hectares to 27.8 thousand hectares. The change in the crop acreages of the main crop species was closely connected to the economic component as long as its yields were directly dependent on the meteorological conditions that varied significantly over the years.

The estimation of productivity and water availability of agrocenoses according to Sentinel-2 was made on the basis of ARVI indexes which were less sensitive to atmospheric influence than NDVI and NDWI which were dependent on the amount of water in a plant. Figure 8 shows changes in the distribution of ARVI and NDWI at the beginning and middle of the vegetational season.

Discussion

The average yield of spring wheat over the 20-year period was 11.6 dt/ha, the maximum one was obtained in a fairly favourable year of 2021 and was equal to 17.9 dt/ha, the minimum one was equal to 6.8 dt/ha in an extremely dry year of 2012. The same situation can be observed for other crops: the average oat yield was 13.5 dt/ha, the maximum one was 18.5 and the minimum one was 7.0; the average buckwheat yield was 6.6 dt/ha and the maximum and minimum ones were 10.6 and 4.3 dt/ha respectively. The average yield of sunflower was at the level of 7.7 dt/ha, the maximum one was also obtained in 2021 – 16.6 dt/ha. In 2012 being a fairly drought tolerant crop it suffered much less from the lack of precipitation than other crops, its yield was 6.6 dt/ha. Since 2016 there has been a sharp rise in the yield of this crop (practically twice) that could probably be explained by the seeding of hybrids. The average soy yield for the 20-year period was 6.8 dt/ha, the maximum one was obtained in 2021 and was equal to 10.6 dt/ha, the minimum one was in 2008 – 3.0 dt/ha. The average yield of corn for feed was at the level of 136.0 dt/ha, the maximum one was obtained in 2019 – 178.4 dt/ha, the minimum one was observed in 2013 and amounted 66.0 dt/ha. The yield of the permanent grasses for green feed averaged 93.6 dt/ha, it reached the maximum one in 2005 – 144.6 dt/ha and the minimum one in 2014 – 41.7 dt/ha. Besides the different weather conditions of vegetational season such a significant variation can be explained by different terms of mowing on an annual basis.

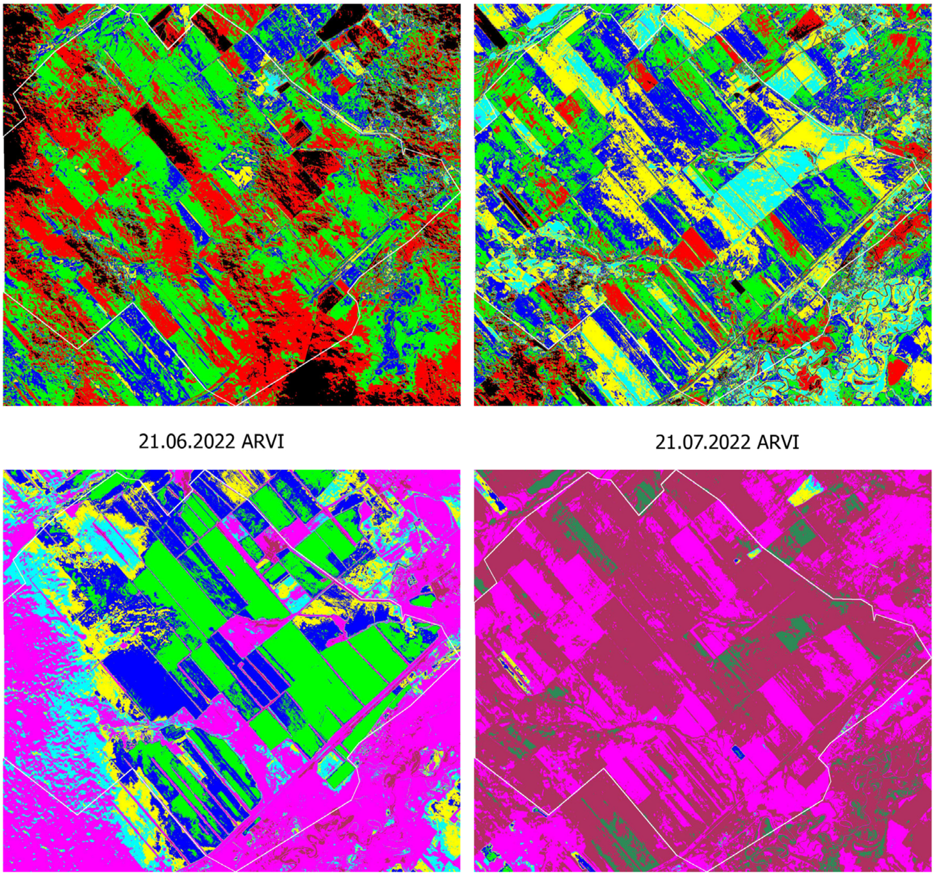
Studies on the influence of intra-field heterogeneity on agricultural crop yields are of particular importance with the use of the information technologies of precision agriculture, since the results obtained, as a rule, indicate the effectiveness of the use of high-intensity agricultural technologies under the conditions of spatial heterogeneity.

As can be seen in Figure 8, the ARVI spatial distribution in the fields is heterogeneous and changes with the crops seeding and their development. Heterogeneous can be noticed in the fields – less productive areas that can be fertilized separately without affecting the main part of the field. You can also follow the terms and area of ploughing fields (in early figures) and harvesting, haymaking. There are no leylands on the territory that prevent the development of weeds. At the same time intensive usage of the territory requires annual monitoring of the erosion activity and performing actions to prevent a soil fertility decrease.

You can see the results of the comparative analysis of the vegetation and water indexes for crops at the beginning and middle of the season below (Fig. 9). The detection of signs of drought was carried out with the help of the NDWI index. Figure 9 clearly shows the difference between cultural and natural communities, figure 8 shows the spatial heterogeneity of the water index within the field. It is noticeable that in the middle of the season NDWI values increased significantly, This is due to the development of crops and vegetation. Therefore, the NDWI index reacts with the sufficient sensitivity to the amount of water in plants. Ground-based data confirms that the greater the phytomass of the agrocenosis, the more water is contained in plants.

Drought is the most fatal phenomenon for plants which is accompanied by an increased background of night and daytime temperature values in the absence of precipitation. Drought is not a fast developing and fast lasting phenomenon since its oset occurs as a result of conglomeration of reasons that cause oppression of plants, therefore, it is necessary to monitor the signs of the onset of drought under favourable conditions for its development over a long period of time. Drought monitoring can be performed by spectral indexes, for example, by NDWI.

The results of a comparative analysis of the vegetation and water indexes for crops at the beginning and middle of the season are shown below (Fig. 9).



Index classes of the research area according to Sentinel

Sequence number	Class colour	ARVI	Crops condition	NDWI	Crops condition
0		0.00-0.19	steam or clouds	-1.00 – -0.51	small amount of water
1		0.20-0.29	emerging crops	-0.50 – -0.26	subsoil
2		0.30-0.39	acceptive	-0.25 – -0.16	tight soil
3		0.40-0.49	average for grain crops	-0.15 – -0.11	moist soil
4		0.50-0.59	above the average	-0.10 – -0.06	reasonably moist
5		0.60-0.69	suitable	-0.05 – -0.01	humid soil
6		0.70-0.79	high productive crops	0.00 – 0.24	high productive agrocenoses, clouds
7		0.80-0.89	shrubs, wood lines	0.25 – 0.49	high productive agrocenoses in humid soils
8		0.90-1.00	tree plantations	0.50 – 0.74	over moist high productive agrocenoses

Figure 8. Maps of productivity and water content of agrocenoses according to Sentinel-2, 2022.

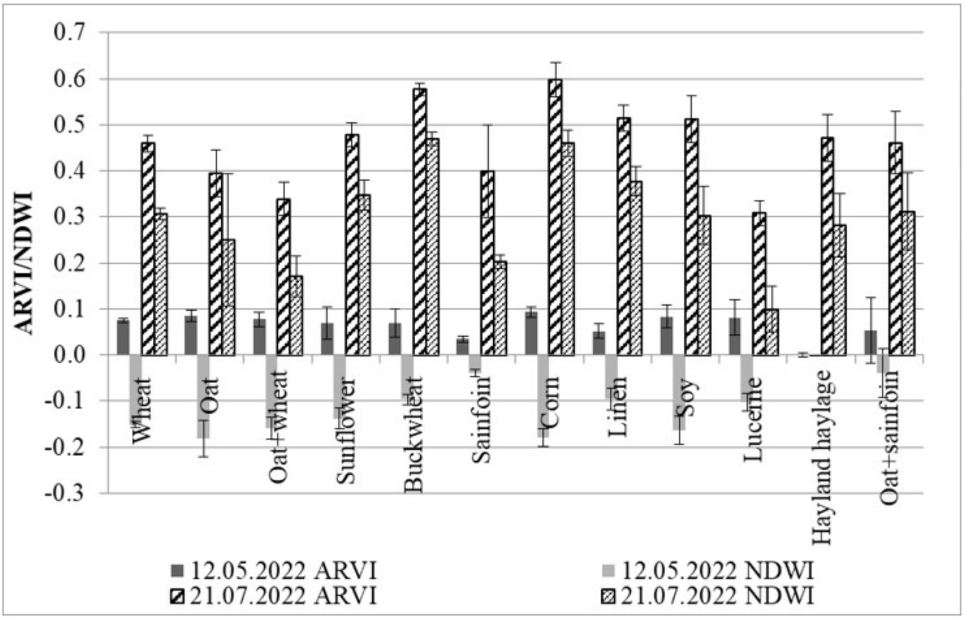


Figure 9. Comparative analysis of ARVI and NDWI values of agrocenoses of monitoring areas at the beginning and middle of a vegetation season according to Sentinel-2.

The lower the value of the NDWI index, the more likely there is a drought in the research area. In general, the lower negative values of the index and the higher the positive ones, the less likely the onset of drought is. Through the error of the arithmetic mean, it is possible to judge how a field is homogeneous according to the water regime. The fields of sunflower and oat with sainfoin had the greatest heterogeneities. The range of values varied for corn, buckwheat, linen and sunflower (Fig. 9) from -0.2(-0.1) to 0.4, hence, these are drought tolerant crops, stress is insignificant. Such crops had a high phytomass. Hayland haylages, seedings of lucerne, sainfoin and oat as natural forage lands practically had a relatively high water index at the beginning of the season (-0.05-0.00) but by the middle of the season its values did not exceed 0.3.

For the main crop of the monitoring areas – wheat, the range of values of the water index varies within insignificant limits from -0.2 to 0.3. There were identified 5 fields with agrocenoses (wheat and lucerne) that were liable to water stress. Agrocenoses with wheat of "Tobolskaia stepnaia" type did not experience much water stress during this period. Oat and soy still have a lower weight than wheat and their range of values is from -0.2 to 0.25. It should be noted that correlation between ARVI and NDWI values was 0.9. This high value shows the dependance of agrocenoses productivity on the level of the territory moistening, implicitly it also indicates relative homogeneity of soil and climate conditions.

The analysis of seasonal dynamics for the most common crops is given below (Fig. 10).

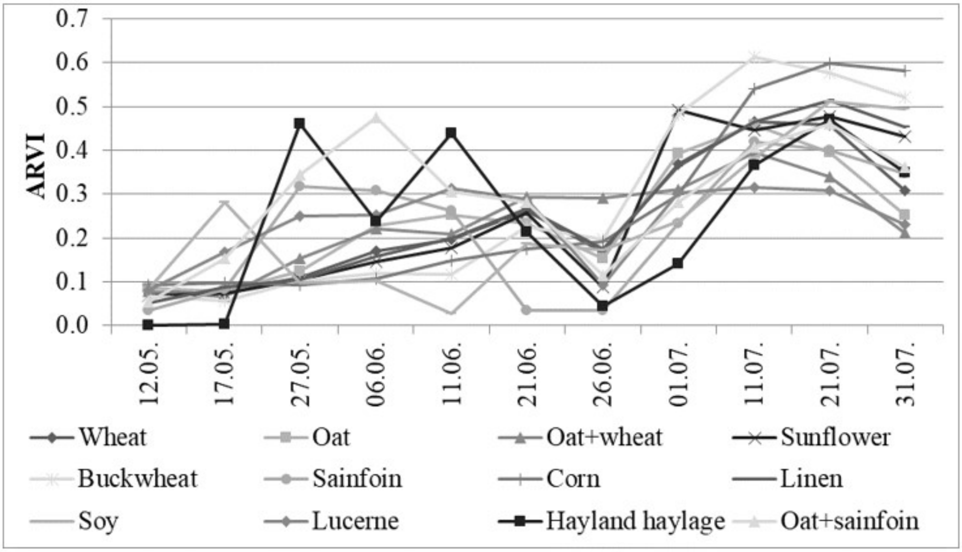


Figure 10. Agrocenoses seasonal dynamics of monitoring areas in 2022 (Sentinel-2, ARVI).

Oat agrocenoses have later terms of intensive development (mainly from 17.05.2022) in comparison with sainfoin (Fig. 10). Most oat fields also had a decrease by 26.06.2022. Peak of development of the oat vegetative mass (paniculation and blooming phase) came by 11.07.2022. Then a decrease connected to the oat entering the fruiting phase (yellowing of plants) followed. Since the decrease was simultaneous within almost all fields, this indicated a low level of weed infestation of crops (their vegetative mass slowed down the index curve).

The development of wheat (Fig. 10) in general resembls the oat seasonal course but the peak of development is shifted further to 06.06.2022 – 11.06.2022. Almost all of the fields got the peak of vegetation development by 11.07.2022 (wheat yellows earlier than oat).

Sunflower as a thermophilic and tall-growing crop had a smooth development starting from 11.06.2022 to 11.072022 and then phytomass smoothly decreased at a low rate.

Linen, buckwheat and corn have high ARVI criteria – the peak was around 0.6 and fairly smooth development. Linen fields had an upward dynamic of development till 31.07.2022. Buckwheat fields had high rates of the vegetation index – parameters of productivity had a low arithmetic mean error, i.e. the crops were friendly and homogeneous. Soy started growing from 11.06.2022. It is worth to notice that a field for soy was ploughed up later (from 27.05 to 11.06.2022) as it is a thermophilic crop. Soy peak of development came on 21.07.2022.

Peak of lucerne development and natural hayland haylages shifted left and fell on 27.05.2022-11.06.2022. Sainfoin maximal development starts from 17.05.2022, in separate fields slightly earlier (these areas heated up better). Sainfoin photosynthesizing masses peak of development was revealed on 11.07.2022. The decrease in sainfoil field vegetation has been going on since 21.07.2022. Most crops showed a decrease in ARVI from 21.06.2022 to 01.07.2022. It is due to shower precipitation and thunder storms during the period (https://www.gismeteo.ru/diary/126044/2022/7/). Because of the rain the ARVI index decreases due to consuming of the part of the near infrared spectrum by water.

Seasonal course of the vegetation curve does not give an idea of the total crops productivity, for this it is necessary to integrate diagrams to receive total values of the ARVI productivity indicator.

As a rule, the higher the indicator of the vegetation index is, the higher agrocenoses productivity (Fig. 11). Wheat has more productivity in average in comparison with oat with the exception of two fields. It is necessary to perform more thorough productivity monitoring within these fields, the reason can also be hidden in the timing of seeding.

We list crops according to the community with relatively small phytomass and projective cover – these are oat+wheat, soy and lucerne. According to the satellite data crops of oat with sainfoil and buckwheat are the most productive.

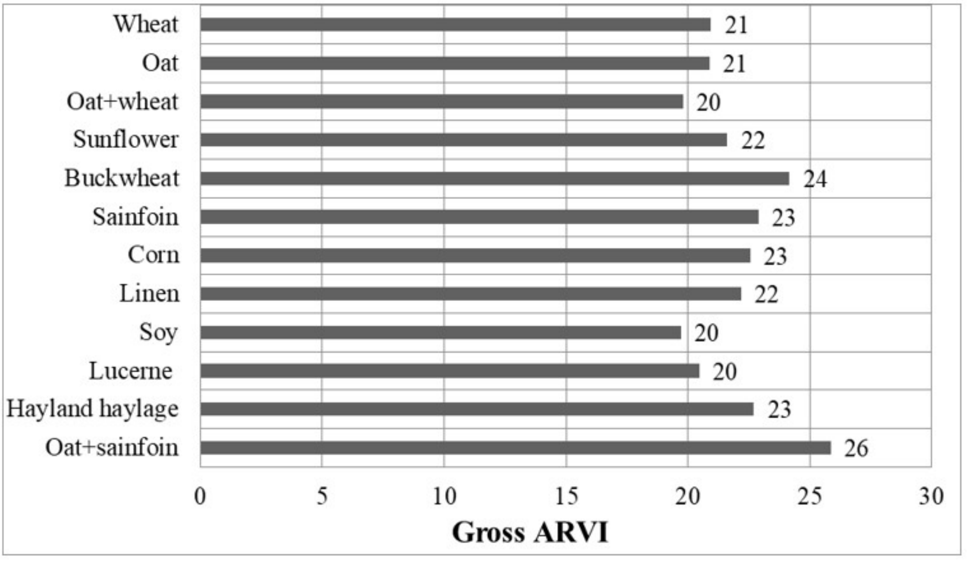


Figure 11. Gross productivity to the ARVI index for agrocenoses of the monitoring areas, Sentinel-2, 2022.

Thus, the ARVI indicator is not an absolute value of vegetation properties at the time of measurement but it gives an idea of relative values that, based on comparison with direct field measurement data, can be recounted into absolute units which characterize vegetation: biomass, chlorophyll content, leaf-area duration, etc. The main advantage of the vegetation indexes is the ease of obtaining them and a wide range of problems solved with their help. Thus, vegetation indexes (ARVI, NDVI) are often used as one of the instruments for performing more complex types of analysis, the result of which can be maps of crops productivity and agricultural lands, maps of agricultural landscapes as long as soil, aridic, phyto-hydrological and phenological maps etc. It is also possible to obtain numerical data on its basis to use in calculations for assessing and predicting yield and crops productivity, biological diversity and the degree of disturbance.

Remote sensing data fraught with the results of ground-based measurements allow to elicit and identify not only areas of heterogeneity within the field territory but also to estimate the direction of a change in the bioproduction process in each of the identified areas. It is important to choose informative indexes of remote and ground-based sensing of the state of plant covering not only from the theoretical standpoint but also for practical objectives especially in the conditions of crops.

Satellite photos are accurate, less time-consuming and a cheaper data source for precision agriculture objectives in comparison with the ground-based research methods.

The technical characteristics of Sentinel-2 allow to identify with the necessary accuracy various vegetation indexes, plant growth and development, moistening and other criteria. For example, it is possible to identify the average index of nitrogen content in spring wheat fields (Osorgin 2020). Further on cartographic data can be used by farm units agronomists for the estimation of the plant condition. The technology of nitrogen determination in agricultural crops based on space technologies is subject to testing for a specific area with the introduction of the correction factors that affect the final result.

It is worth noting that detailed maps of growth stages of agricultural crops have a crucial significance for agromonitoring and food security. The crops growth stages are usually monitored with the help of high-resolution satellite photos. Though accurate mapping is troubled because of the appearance of mixed pixels on fragmented and heterogenic fields as well as cloud cover. To solve these problems, automated algorithms are being developed to create multitemporal maps of growth stages in near real time with a spatial resolution of 10 m (Ramadhani 2020). The value accuracy ranges from 78.3% to 90.6%.

In our opinion, the Sentinel-2 photos contribution for the valuation of projective cover and phytomass is emphasized by several authors. For example, Sentinel data was used for the analysis of the variability of the projective cover within the frames of fields under cultivation according to the NDVI data, the actual values of the projective cover (more than 200 measurements) of crops were taken for designing a model. Three different methods for which an estimation of efficiency was performed were used for calculation of a projective cover based on satellite data. The first method was to recalculate NDVI values measured in accordance with the Sentinel data into the projective cover values. The second method was similar to the first one but it was based on MOD13Q1 data. The third method was to calculate the projective cover in accordance with the Sentinel-2 data based on the algorithm that used a trained neural network implemented in SNAP (Sentinel Application Platform) software. The correlation factor between actual and remotely indicated values according Sentinel data ranged from 0.74 to 0.9. It is shown that calculated data reliably reflects seasonal changes of plant covering in fields with different types of crops: soy, corn, sunflower and permanent grasses. During periods of maximum projective cover with green phytomass seedings are characterized by high homogeneity and the lowest values of the variation factor. During this period estimation of their condition and harvest forecast are possible (Terekhin 2019).

Sentinel-2 satellite data is also suitable for estimation of soil moisture in agrocenoses as long as fallow lands (Liu et al. 2021; Sačkov et al. 2021).

Conclusion

The analysis of the obtained data showed that the planting acreages of the main agricultural crops for the period of 2001-2021 changed according to the economic component, the share of more profitable crops increased at the expense of the rest. The yield of agricultural crops at the overall upward trend changed substantively annually depending on weather conditions and it showed the average minimum in an extremely dry year of 2012 and maximum in a year of 2021.

When estimating water content and water stress of agrocenoses according to Sentinel-2 it was identified that for sainfoin, linen and sunflower the value range varies from -0.2 to 0.4, therefore, these are drought tolerant crops, stress is insignificant. Crops with sainfoin did not have any negative values. Lucerne and corn were within the range of the indicated values. For wheat the value range varied from -0.2 to 0.3. Buckwheat agrocenoses have a high phytomass and value ranges from -0.1 to 0.45, therefore, the crop is sufficiently water supplied. Oat and soy crops have a lower phytomass than wheat and their value range varies from -0.2 to 0.25.

Thus, the estimation of the agrocenoses productivity according to the Sentinel-2 identified heterogeneities in the fields – less productive areas that can be fertilized separately without affecting the main part of the field.

On the basis of this data, maps of crops productivity and agricultural lands can be prepared including for the purposes of variable rate fertilizer application.

The analysis of remote sensing data of high-resolution satellite photos allows to solve problems of researching of the soil hydrological regime, establishing water supply sources and monitoring unfavourable meteorological phenomena.

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