https://doi.org/10.31489/2024BMG1/150-158

UDC 911.2 (574.2)

Received: October 16 2023 | Accepted: December 14 2023

F.K. Kiryanov-Gref[1], A.V. Khoroshev[1*], K.A. Anatskaya[2]

[1]*Lomonosov Moscow State University, Faculty of Geography, Moscow, Russia;*
[2]*Institute of Geography and Nature Management, Astana International Scientific Complex, Astana, Kazakhstan*
**Corresponding author: avkh1970@yandex.ru*

Factors of intra-field phytomass variability in steppe agricultural landscapes of Kazakhstan

The yield of grain crops and its predictability largely depends on the intra-field heterogeneity of landscape conditions. We used the example of steppe agricultural landscapes in the Akmola region to solve the following objectives: 1) to evaluate the informative value of NDVI for assessing yield depending on hydrothermal conditions; 2) to determine the effect of intra-field patchiness on NDVI values and yield; 3) to determine the dependence of intra-field variation of phytomass on the tract and facies structure and hydrothermal conditions. We used data on wheat and barley yields and intra-field NDVI variability in 80 field plots in 2009–2013, data on the tract and facies structure, and hydrothermal parameters. We studied the relationships between spatial and temporal variability of phytomass, landscape and hydrothermal factors by means of correlation and variance analysis. It was established that NDVI was only partially informative for direct assessment of grain yield. The index values for July dates better reflect the yield than in June and August. The hypothesis that NDVI patchiness in the field area depends on the cultivated crop was not confirmed. The yield in fields with complex facies structure is usually lower than in homogeneous fields. In dry years, the intra-field variation of phytomass is less pronounced than in wet years. The proximity to the hill is a significant factor that increases the spatial variability of phytomass due to the additional introduction of moisture and sediment along the rills. High facies patchiness either reduces yield or increases its temporal variability and reduces predictability.

Keywords: landscape, facies structure, patchiness, yield, NDVI, variability, hydrothermal conditions, neighborhood.

Introduction

The internal heterogeneity of field plots has a significant impact on crop predictability. This heterogeneity is expressed in different trophic and moisture characteristics of the soil, due to the mosaic microlandforms or even the presence of several meso-landforms, that is, *facies* or *tract* (*Facies* in Russian-speaking countries is understood as an elementary landscape unit that has uniform micro-landform, soil, phytocenosis. *Tract* is a combination of facies with common genesis (e.g., erosion) within the meso-landform (e.g., gully, hill, flat interfluve etc.) structure. These results in difficulties in assessing the relationship between crop yields and in-field mosaics. The interests of agricultural science and landscape science intersect in this issue. During the past two decades, landscape science has given priority attention to the relationship between spatial and temporal scales of dynamic changes in structure and functioning [1, 2]. Spatial variability of the vegetation cover of agricultural landscapes is usually explained by changes in the process of plant development and agricultural technologies [3]. Numerous studies found evidence that phytoproductivity depends on the hydrothermal parameters of the territory [4, 5]. For steppe types of agrolandscapes, the variation of humidification conditions is of key importance [6].

New opportunities for studying the spatial aspect of the phytoproduction process and its dynamics are provided by the increased availability of remote sensing and the calculation of vegetation indices with different variations in the combination of spectral channels of satellite images, which allow us to assess the quality and quantity of aboveground phytomass. The normalized difference vegetation index (NDVI) is most commonly used as an indicator of the amount of photosynthetically active biomass, its seasonal and long-term dynamics of vegetation productivity [7]. It was found that NDVI reflects well the parameters of vegetation productivity in general and agricultural crops in particular [8]. The efforts of most researchers using vegetation indices in the last decade have focused either on determining the informative value of indices in relation to the measured phytomass [9, 10], or on identifying trends in phytoproductivity due to climate changes [11, 12], but mostly without taking into account intra-landscape differences in the sensitivity of phytocenoses. Studies of the long-term dynamics of NDVI are usually based on the analysis of its averaged or integrated values over sufficiently long intervals using low-resolution data (below 5 km) [13, 14]. The spatial non-stationarity of the relationship between NDVI and climate factors has been established [15, 16]. Studies of the influence of local edaphic and geomorphological factors on the spatial variability of the phytoproduction process are less numerous [7, 17]. It was proved that the causes of uneven crop yields in the agrolandscapes were variations in the content of macro- and microelements and pre-sowing soil moisture [18].

The aim of the study is to identify factors of spatial and temporal intra-field variability of phytomass on the example of agricultural landscapes in the steppe zone of northern Kazakhstan. NDVI data were used to assess the amount of phytomass and its dynamics. The following tasks were solved: 1) to evaluate the informative value of NDVI for assessing yield depending on hydrothermal conditions; 2) to determine the effect of intra-field patchiness on NDVI values and yield; 3) to determine the dependence of intra-field variation of phytomass on the tract and facies structure and hydrothermal conditions.

Experimental

The research area is located in Bulandy district of Akmola region in the vicinity of Kapitonovka village. The territory belongs to the landscape of the lacustrine and alluvial plain, composed of Neogene sandy-clay deposits overlain by middle and Upper Quaternary ancient proluvial loess-like loams with a thickness of 20-30 m, with southern carbonate heavy loamy chernozems, formerly under the steppe dominated by *Stipa zalesskii* and forbs [19]. The landscape structure is dominated by slightly inclined watershed surfaces. Subdominant tracts were shaped by erosion or suffosion, some of them are plowed. They have a significant impact on the sensitivity of yield to hydrothermal conditions [20]. From the east, the agricultural landscape borders a forested hill composed of sandstones and effusive igneous rocks of the Lower Ordovician age. The study area has a continental climate. The average annual temperature is about 2.4° C; July temperatures range from 17.5° C to 22.3° C. To a greater extent, the average annual precipitation varies from 275 mm in dry years to 550 mm in wet years. The main amount of precipitation falls in the summer months; the maximum often falls in July — from 40 mm to 137 mm per month [21].

Data on the yield of wheat and barley in 2009–2013 were provided by agricultural unit Zhuravlevka-1 for 80 fieldplots with a total area of about 48.5 thousand ha, with an average area of 402 ha. 11 scenes of satellite images were obtained from the US Geological Survey (USGS) Earth Explorer: Landsat 5 TM (09.06.2009, 28.06.2010, 30.07.2010, 15.06.2011, 17.07.2011), Landsat 7 ETM+ (30.07.2010, 11.07.2012, 12.08.2012, 20.06.2013, 30.07.2013) and Landsat 8 (15.08.2013). A digital terrain model SRTM with a resolution of 30 m was obtained from the same site. In the SAGA GIS 7.3.0 (Residual Analysis function), the slope gradients were smoothed by averaging over 7 pixels and calculating the average and median values for each field. We used data on average monthly temperatures and precipitation for 2009–2013 [21].

In STATISTICA 7.0 software, descriptive statistics of NDVI were calculated for each field, for each of the 11 dates: mean, standard deviation, minimum, maximum, quartiles (25% and 75%), median, percentiles (10% and 90%). Data on the proportions of subdominant erosion and suffosion-shaped tracts were used as explanatory variables [20]. To test the hypothesis about the relationship between wheat and barley yields and NDVI, nonparametric Spearman correlations (Ksp) were calculated, the choice of which is justified by the deviation of the raw data from the normal distribution. To estimate the intra-field variation of NDVI, we used the standard deviation and frequency of the modal interval (when dividing the range of values into intervals with a step of 0.1). For comparability of data for different years and seasons, the data were ranked by the values of the standard deviation as a percentage of the maximum value (the smaller the spatial variability of values, the higher the rank). By means of cluster analysis (k-means method), the fields were grouped into 3 classes based on the set of standard deviation values and NDVI modal interval frequencies. Fields were classified into facies mosaic classes based on visual analysis of the images from the Google Earth Pro portal. We used the criterion of the proportion of territories with facies patchiness: 0–10%, 10–50%, 50–90% and more than 90% of the area. The fields were also classified according to whether they belong to a watershed, near-valley, or near-hill terrain.

SAGA GIS 7.3.0 software was used to calculate the Moran index (Global Moran's I for Grids function) for each field and date, indicating the presence of spatial autocorrelation in NDVI values. The Moran index takes values of 1 at clustered distribution of values, 0 at a completely chaotic distribution, and -1 in case of the “chessboard-like” neighborhood of clusters with opposite values. The significance of statistical differences between classes of fields has been estimated by the Fisher and Newman-Keuls statistics. Box-Whisker plot was used to visualize the results.

Results

The four mosaic classes of fields identified from satellite images clearly differ in terms of terrain conditions: the most monotonous fields occur on watershed surfaces, and the most mosaic fields — in areas with rills. The greater the average slope gradient and the greater the proportion of hill slope hollows, and rills within the field area, the higher the facies patchiness. Mosaic classes reflect the grain yield to some extent: the most mosaic fields (Class 1) have a wheat yield of no more than 8 centers per ha, while other classes — up to 18 centers/ha. Consequently, in fields with a complex facies structure, the yield is usually lower than in more monotonous fields.

We tested the hypothesis of a direct relationship between grain yield and the average NDVI for the field plot. The hypothesis was confirmed (Ksp=0.42) only for two dates: 11.07.2010 and 30.07.2012. This corresponds to the dates closest to the period of maximum role of photosynthetic organs in the formation of grain mass [22]. For the rest of the time periods, the correlations were insignificant.

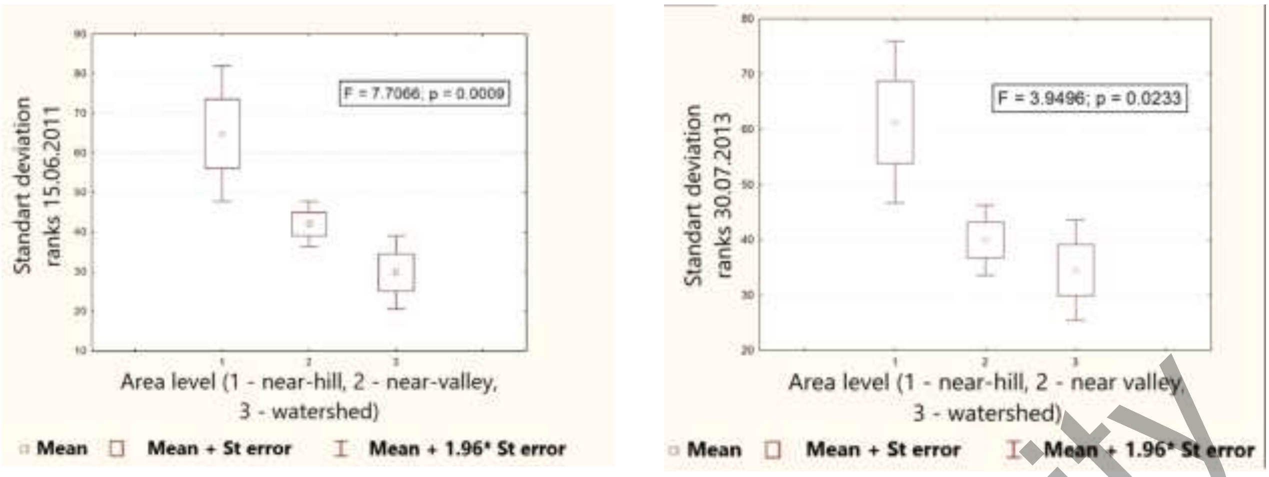
To test the hypotheses about the dependence of NDVI mosaics in the field area on the cultivated crop, we compared the values of the standard deviation and the frequency of the modal interval for two neighboring fields with the same landscape position and internal structure, but sown with different crops (wheat and barley). The hypothesis was not confirmed. The number of dates when the wheat field was more uniform than the barley field does not differ from the opposite case.

It is known that intra-field variability of phytomass is often determined by the presence of micro- and meso-landforms [7]. For the June dates of 2009, 2011, and 2013, we revealed a weak positive dependence (Ksp 0.24...0.29) of the NDVI standard deviation on the total share of concave landforms within the field area. In July and August, the intra-field NDVI variability increases as the share of hill slope hollows increases (Ksp=0.29). On the other hand, the Moran index (Fig. 1) in many cases deviates significantly from 0 and values of 0.7-0.8 prevail in each term, which indicates the clustered NDVI values. In June, the presence of a certain proportion of suffosion valleys in the field always corresponds to a high value of the Moran index: the correlation is significant and positive (Ksp 0.32...0.48). Even among fields with zero or minimal fraction of erosion and suffusion tracts, the Moran index can reach values of 0.7-0.9.

a b

Figure 1. Moran index for field plots calculated from the NDVI values for 09.06.2009 (a) and 07.08.2010 (b)

Intra-field variation of NDVI as an indicator of the green phytomass differs by the terrains identified by the combination of tracts and positional factor. For the majority of terms, the intra-field variation of NDVI is stably higher in the near-hill terrain (Fig. 2) than in the near-valley and watershed areas. In the near-valley terrain, the intra-field variation is usually higher than in the watershed terrain, but the differences are not always significant.



a b

Figure 2. Variation of the values of the ranks of the NDVI standard deviation in field plots in the terrain classes (near-hill, near-valley, watershed) of 15.06.2011 (a) and 30.07.2013 (b). F – Fisher statistics, p – significance level

Based on the frequency of the NDVI modal interval, it was found that in hot and dry years (2010 and 2012), there were almost no differences between terrains, and in wet and cold year (2011, 2013), the differences were better manifested. This is due to the low yield in dry years in almost all fields: 95% of wheat fields yielded no more than 10 c/ha in 2010 and 14 c/ha in 2012. In wet years, within the near-hill terrain, the modal interval NDVI frequency is lower, that is, the green phytomass varies in a larger range of values than in the near-valley and watershed terrains.

Fields with consistently large range of NDVI values are located on steeper slopes, and also have a larger percentage of subdominant tracts of valleys, hill slope hollows, and rills. They occur mostly within near-hill terrain or valley slopes (Fig. 3).

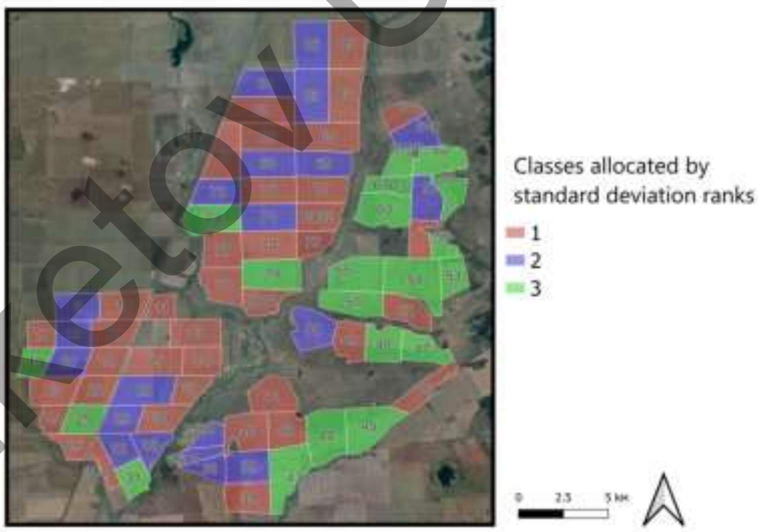


Figure 3. Map of the classes of fields selected by the ranks of the standard deviation of NDVI values for 2009–2013 within the fields by the method of cluster analysis (k-means). Fields with a consistently high spatial variation of NDVI (class 3) are concentrated in the upland near-hill terrain in the eastern sector of the territory

Now we turn to the analysis of the relationship between the parameters of intra-field variation of green phytomass (indicated by NDVI) and the indicator of stability of grain yield. The fields were divided into 4 classes: 1 — fields with yield consistently above the average (stable «leaders»), 2 — fields with high variability from year to year, 3 — fields with a stable average yield, never reaching the maximum or minimum values, 4 — fields with yield consistently below average, in some years minimal, on the farm (stable “losers”) (Fig. 4). Most fields with stable low yields occur in near-valley terrain.

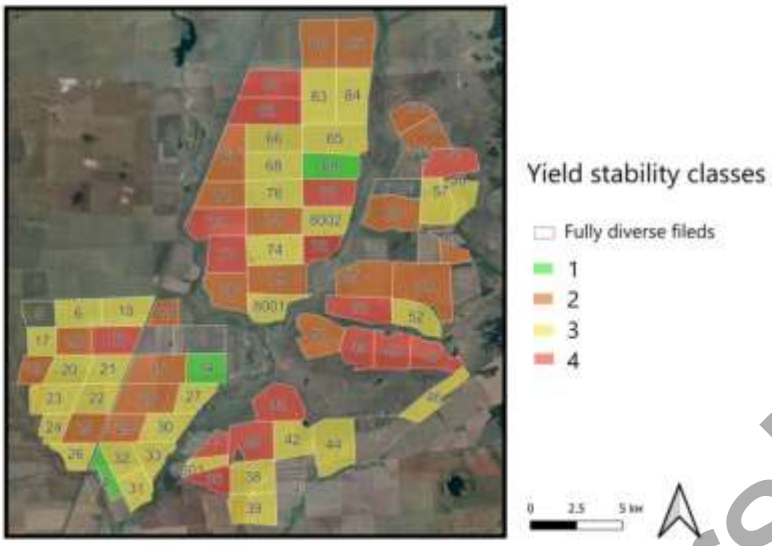


Figure 4. Field yield stability class s: 1 — stable “leaders”, 2 — with high variability from year to year, 3 — with stable average yield, 4 — stable “losers”

Analysis of the relationship between yield stability classes and standard deviation rank classes of NDVI values showed the following. Fields with stable high yield (“leaders”) never belong to the classes with largest NDVI spatial variation. Average values of intra-field variation of phytomass (standard deviation) are located mainly among fields with consistently average yields.

Analysis of the conjugacy of facies mosaic classes and grain yield stability classes showed that fields with maximum patchiness cannot be stable leaders in yield (Fig. 5). The number of stable “loser” fields increases as patchiness increases. The most monotonous fields and fields with variation in less than 50% of the area mainly belong to the group with a stable average grain yield.

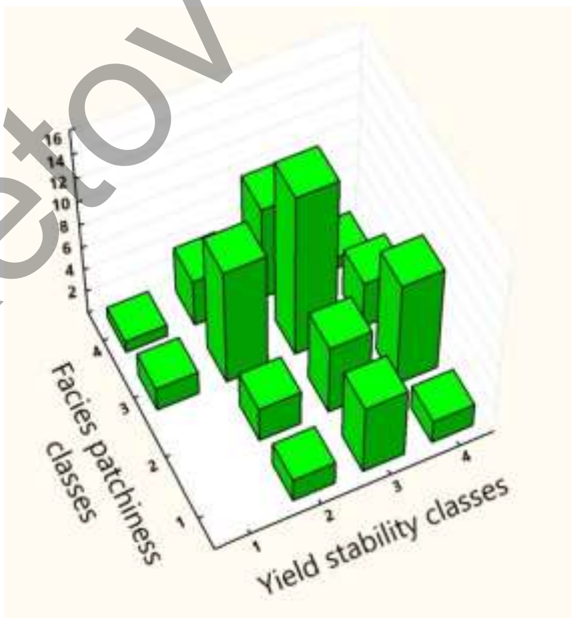


Figure 5. Distribution of frequency of fields between the classes of facies patchiness (1 — maximum, 4 — minimum) and yield stability classes (1 — stable “leaders”, 2 — high variability from year to year, 3 — stable average yield, 4 — stable “losers”)

Discussions

NDVI cannot be considered an informative indicator for assessing and predicting grain yields, at least not under any hydrothermal conditions. NDVI, by definition, shows the entire green mass (leaves, stems, etc.), and the measured yield indicates the grain mass. However, this is true only when analyzing the yield of grain crops; for example, when evaluating forage areas, NDVI can provide a direct estimate of yield [23]. During the entire growing season, photosynthesis plays a crucial role in the accumulation of ear biomass directly during the filling period, which takes place in mid-July [22]. Our study showed that, all other things being equal, facies patchiness manifests itself in the spatial variability of green phytomass, regardless of the crop type.

Significant clustering of NDVI values (according to the Moran index) with a weak dependence on the share of concave landforms means that the spatial variability of phytomass depends on local scale factors: facies patchiness (which is not captured by the available topographic data) or features of agricultural machinery activity.

The increase in the NDVI variation in wet years in near-hill terrain, compared with near-valley and watershed ones, is explained by the fact that during rain precipitation and snowmelt, additional moisture and sediments enter the plowed erosion-shaped landforms, which slightly increases the phytomass. Eroded slopes of convex positions, on the contrary, have smaller values.

The intra-field variation of NDVI values, i.e., the amount of green phytomass of cultivated crops, depends on the facies patchiness. Facies patchiness, in turn, is determined by the location (geographical location) of the field and its average slope: the steeper the slope and the more numerous erosion-shaped landforms, the higher the facies diversity. In the studied agricultural landscape, a neighborhood factor contributes as well: the matter input from the adjacent hill increases the variation of phytomass in the fields. Thus, facies patchiness creates conditions that either reduce the yield or make the yield unstable from year to year, and therefore less predictable.

Conclusions

1. The vegetation index NDVI is only partially informative for direct assessment of grain yield. The index values for July dates better reflect the yield than in June and August.
2. The hypothesis about the dependence of NDVI variation in the field area on the cultivated crop under the same landscape conditions was not confirmed.
3. The yield in fields with complex facies structure is usually lower than in homogeneous fields.
4. In dry years, intra-field variation of phytomass due to facies heterogeneity is less pronounced than in wet years.
5. The proximity to the hill is a significant factor that increases the spatial variability of phytomass due to the input of moisture and sediments along the erosion-shaped landforms.
6. High facial patchiness either reduces yields or increases their temporal variability and predictability.

Acknowledgments

The study was carried out within the framework of the State Task of the Faculty of Geography of Lomonosov Moscow State University No. 121051300176-1 “Factors and processes of spatial and temporal organization of natural and anthropogenic landscapes”.

References

1 Antrop M. Landscape Perspectives. The Holistic Nature of Landscape / M. Antrop, V. van Eetvelde. — Springer, Dordrecht, The Netherlands, 2017. — 436 p.

2 With K.A. Essentials of landscape ecology / K.A. With. — Oxford: Oxford University Press, 2019. — 641 p.

3 Шукилович А.Ю. Применение сенсора MODIS для оперативного мониторинга земель сельскохозяйственного назначения / А.Ю. Шукилович, Е.В. Федотова, Ю.А. Маглинец // Журн. Сиб. федерал. ун-та. Техника и технологии. — 2016. — № 9 (7). — С. 1035–1044.

4 Михайлов Н.Н. Использование временных рядов вегетационного индекса NDVI для мониторинга растительного покрова степной зоны Западной Сибири / Н.Н. Михайлов, Л.А. Михайлова, Н.Ф. Харламова, Ч. Лхагвасурэн // Научные ведомости Белгород. гос. ун-та. Сер. Естественные науки. — 2010. — № 15(86). — С. 25–33.

5 Шинкаренко С.С. Сезонная динамика NDVI пастбищных ландшафтов Северного Прикаспия по данным MODIS / С.С. Шинкаренко, С.А. Барталев // Современные проблемы дистанционного зондирования Земли из космоса. — 2020. — Т. 17, № 4. — С. 179–194.

6 Страшная А.И. Прогнозирование урожайности зерновых культур на основе комплексирования наземных и спутниковых данных в субъектах Южного федерального округа / А.И. Страшная, О.В. Береза, П.С. Кланг // Гидрометеорологические исследования и прогнозы. — 2021. — № 2(380). — С. 111–137.

7 Гопп Н.В. Оценка влияния мезорельефа склона на пространственную изменчивость свойств почвы и характеристики растительного покрова по данным дистанционного зондирования земли / Н.В. Гопп, Т.В. Нечаева, О.А. Савенков // Исследование Земли из космоса. — 2016. — № 3. — С. 66–74.

8 Терехин Э.А. Сезонная динамика проективного покрытия растительности агроэкосистем на основе спектральной спутниковой информации / ЭА. Терехин // Современные проблемы дистанционного зондирования Земли из космоса. — 2019. — Т. 16, № 4. — С. 111–123.

9 Лиджиева Н.Ц. Опыт применения индекса вегетации (NDVI) для определения биологической продуктивности фитоценозов аридной зоны на примере региона черные земли / Н.Ц. Лиджиева, С.С. Уланова, Н.Л. Федорова // Изв. Саратов. ун-та. Сер. Химия. Биология. Экология. — 2012. — Т. 12. — Вып. 2.

10 Гулянов Ю.А. Мониторинг фитометрических параметров с использованием инновационных методов сканирования посевов / Ю.А. Гулянов // Таврич. вестн. аграрной науки. — 2019. — № 3(19). — С. 64–76. https://doi.org/10.33952/2542-0720-2019-3-19-64-76

11 Шевырногов А.П. Определение границ биомов на территории Евразии по динамике дисперсии NDVI на основе спутникового мониторинга / А.П. Шевырногов, А.А. Ларько, Г.С. Высоцкая, Л.А. Сомова // Успехи современного естествознания. — 2019. — № 1. — С. 123–128.

12 Han J.C. Characterization of elevation and land cover dependent trends of NDVI variations in the Hexi region, northwest China / J.C. Han, Y. Huang, H. Zhang, X. Wu // Journal of Environmental Management. — 2019. — Vol. 232. — P. 1037–1048.

13 Золотокрылин А.Н. Динамика летнего увлажнения и биофизических параметров аридных пастбищ Европейской части России в 2000–2014 гг. / А.Н. Золотокрылин, Т.Б. Титкова, Е.А. Черенкова, В.В. Виноградова // Аридные экосистемы. — 2016. — Т. 22, № 1(66). — С. 5–10.

14 Тельнова Н.О. Выявление и картографирование многолетних трендов NDVI для оценки вклада изменений климата в динамику биологической продуктивности агроэкосистем лесостепной и степной зон Северной Евразии / Н.О. Тельнова // Современные проблемы дистанционного зондирования Земли из космоса. — 2017. — Т. 14, № 6. — С. 97–107.

15 Gao Y. Spatial pattern of non-stationarity and scale-dependent relationships between NDVI and climatic factors — A case study in Qinghai-Tibet Plateau, China / Y. Gao, J. Huang, S. Li, Sh. Li // Ecological Indicators. — 2012. — Vol. 20. — P. 170–176.

16 Zhao Z. Exploring spatially variable relationships between NDVI and climatic factors in a transition zone using geographically weighted regression / Z. Zhao, J. Gao, Y. Wang, J. Liu, S. Li // Theoretical and Applied Climatology. — 2015. — Vol. 120(3-4). — P. 507–519. https://doi.org/10.1007/s00704-014-1188-x

17 Жуков А.В. Ландшафтная экология как основа пространственного анализа продуктивности агроценозов / А.В. Жуков, О.Н. Кунах, Г.А. Задорожная, Е.В. Андрусевич // Ecology and noospherology. — 2013. — Вып. 24. —№ 1–2. — С. 68–80.

18 Гопп Н.В. Цифровое картографирование пространственной изменчивости параметров почв и растительности на юго-востоке Западной Сибири: дис. … д-ра биол. наук / Н.В. Гопп. — Новосибирск: Ин-т почвоведения и агрохимии СО РАН, 2021. — 269 с.

19 Николаев В.А. Ландшафты азиатских степей / В.А. Николаев. — М.: Моск. гос. ун-т, 1999. — 288 с.

20 Хорошев А.В. Влияние ландшафтных условий на урожайность зерновых культур в степной зоне Северного Казахстана / А.В. Хорошев, К.А. Ткач, Д.У. Муртазина // Вестн. Моск. ун-та. Сер. 5. География. — 2018. — № 3. — С. 62–69.

21 Погода и климат. — [Электронный ресурс]. — Режим доступа: www.pogodaiklimat.ru

22 Хоконова М.Б. Закономерности налива и прироста сухой биомассы яровой пшеницы / М.Б. Хоконова, А.А. Аджиева // Изв. Кабард.-Балкар. гос. аграр. ун-та им. В.М. Кокова. — 2016. — С. 6.

23 Ерошенко Ф.В. Возможности дистанционной оценки состояния и степени деградации природных кормовых угодий / Ф.В. Ерошенко, С.А. Барталев, Н.Г. Лапенко // Современные проблемы дистанционного зондирования Земли из космоса. — 2018. — Т. 15, № 7. — С. 53–66.

Ф.К. Кирьянов-Греф, А.В. Хорошев, К.А. Анацкая

Қазақстанның дала агроландшафтарындағы фитомассаның егістік ішілік өзгергіштік факторлары

Дәнді дақылдардың шығымдылығы және оның болжамдылығы көбінесе ландшафтық жағдайлардың егістік ішіндегі әркелкілігіне байланысты. Ақмола облысының далалық егіншілік ландшафтарын мысалға ала отырып, келесі міндеттер шешілді: 1) гидротермиялық жағдайларға байланысты өнімділікті бағалау үшін NDVI ақпараттық мазмұнын бағалау; 2) егістік ішілік теңбілдіктің NDVI мәндері мен шығымдылығына әсерін анықтау; 3) фитомассадағы егістік ішілік вариацияның жер мен бет құрылымына және гидротермиялық жағдайларға тәуелділігін белгілеу. 2009-2013 жылдардағы 80 егістік учаскелеріндегі бидай мен арпаның шығымдылығы және NDVI-ның егістік ішілік өзгергіштігі туралы деректер, елдімекен және фациальды құрылым туралы мәліметтер, гидротермиялық параметрлер туралы мәліметтер пайдаланылды. Фитомассаның кеңістіктік және уақыттық өзгергіштігі, ландшафтық және гидротермиялық факторлар арасындағы байланыс корреляциялық және дисперсиялық талдау әдістерін қолдану арқылы зерттелді. NDVI астық шығымдылығын тікелей бағалау үшін шектеулі ғана ақпарат беретіні анықталды. Шілде күндері үшін индекс мәндері маусым және тамыз айларына қарағанда жақсы кірісті көрсетеді. Егістік алқаптағы NDVI теңбілдік көрсеткіштерінің өсірілген дақылға тәуелділігі туралы гипотеза расталмады. Күрделі фациялық құрылымы бар танаптардағы шығымдылық әдетте біртекті егістіктерге қарағанда төмен. Құрғақшылық жылдары фитомассадағы егістік ішілік вариация ылғалды жылдарға қарағанда азырақ байқалады. Төбе массивіне жақын орналасуы эрозия үйінділерінен ылғал мен шөгінділердің қосымша берілуі есебінен фитомассаның кеңістіктік өзгермелілігін арттыратын маңызды фактор болып табылады. Жоғары фациялы теңбілдік өнімділікті төмендетеді немесе оның уақытша өзгергіштігінің артуына және болжамдылықтың төмендеуіне ықпал етеді.

Кілт сөздер: ландшафт, фация құрылымы, теңбілдік, өнімділік, NDVI, өзгергіштік, гидротермиялық жағдайлар, көршілестік.

Ф.К. Кирьянов-Греф, А.В. Хорошев, К.А. Анацкая

Факторы внутриполевой изменчивости фитомассы в степных агроландшафтах Казахстана

Урожайность зерновых культур и ее прогнозируемость в значительной степени зависят от внутриполевой неоднородности ландшафтных условий. На примере степных агроландшафтов Акмолинской области решались задачи: 1) оценить информативность NDVI для оценки урожайности в зависимости от гидротермических условий; 2) установить влияние внутриполевой мозаичности на значения NDVI и урожайность; 3) определить зависимость внутриполевого варьирования фитомассы от урочищной и фациальной структуры и гидротермических условий. Использовались данные об урожайности пшеницы и ячменя и внутриполевой вариабельности NDVI на 80 полевых участках в 2009–2013 гг., сведения об урочищной и фациальной структуре, гидротермические параметры. Отношения между пространственной и временной изменчивостью фитомассы, ландшафтными и гидротермическими факторами исследовались методами корреляционного и дисперсионного анализа. Установлено, что NDVI лишь ограниченно информативен для прямой оценки урожайности зерна. Значения индекса за июльские даты лучше июньских и августовских отражают урожайность. Гипотеза о зависимости показателей мозаичности NDVI на полевом участке от возделываемой культуры не подтвердилась. Урожайность на полях со сложным фациальным строением обычно ниже, чем на однородных полях. В сухие годы внутриполевое варьирование фитомассы проявляется в меньшей степени, чем во влажные годы. Соседство с сопочным массивом является существенным фактором, повышающим пространственную вариабельность фитомассы за счет дополнительного привноса влаги и наносов по эрозионной. Высокая фациальная мозаичность либо снижает урожайность, либо способствует росту ее временной изменчивости и уменьшению прогнозируемости.

Ключевые слова: ландшафт, фациальная структура, мозаичность, урожайность, NDVI, изменчивость, гидротермические условия, соседство.

References

1 Antrop, M. & van Eetvelde, V. (2017). *Landscape Perspectives. The Holistic Nature of Landscape*. Springer, Dordrecht, The Netherlands.

2 With, K.A. (2019). *Essentials of landscape ecology*. Oxford: Oxford University Press.

3 Shukilovich, A.Yu., Fedotova, E.V., & Maglinetc, Yu.A. (2016). Primenenie sensora MODIS dlia operativnogo monitoringa zemel selskohoziaistvennogo naznacheniia [Application of MODIS sensor for operational monitoring of agricultural lands]. *Zhurnal Sibirskogo federalnogo universiteta. Tekhnika i tekhnologii — Journal of Siberian Federal University. Techniques and technologies, 9* (7), 1035–1044 [in Russian].

4 Mihailov, N.N., Mihailova, L.A., Harlamova, N.F., & Lhagvasuren, Ch. (2010). Ispolzovanie vremennykh riadov vegetatsionnogo indeksa NDVI dlia monitoringa rastitelnogo pokrova stepnoi zony Zapadnoi Sibiri [Use of NDVI vegetation index time series for monitoring vegetation cover of the steppe zone of Western Siberia]. *Nauchnye vedomosti Belgorodskogo gosudarstvennogo universiteta. Seriia Estestvennye nauki — Scientific proceedings of Belgorod State University. Series Natural Science, 15*(86), 25–33 [in Russian].

5 Shinkarenko, S.S. & Bartalev, S.A. (2020). Sezonnaia dinamika NDVI pastbishchnykh landshaftov Severnogo Prikaspiia po dannym MODIS [Seasonal dynamics of NDVI of pasture landscapes of the Northern Pre-Caspian according to MODIS data]. *Sovremennye problemy distantsionnogo zondirovaniia Zemli iz kosmosa — Modern problems of remote sensing of the Earth from space, 17*(4), 179–194 [in Russian].

6 Strashnaia, A.I., Bereza, O.V., & Clang, P.S. (2021). Prognozirovanie urozhainosti zernovykh kultur na osnove kompleksirovaniia nazemnykh i sputnikovykh dannykh v subektakh Yuzhnogo federalnogo okruga [Forecasting of grain crop yields on the basis of ground and satellite data integration in the subjects of the Southern Federal District]. *Gidrometeorologicheskie issledovaniia i prognozy — Hydrometeorological studies and forecasts, 2* (380), 111–137 [in Russian].

7 Gopp, N.V., Nechaeva, T.V., & Savenkov, O.A. (2016). Otsenka vliianiia mezorelefa sklona na prostranstvennuiu izmenchivost svoistv pochvy i kharakteristiki rastitelnogo pokrova po dannym distantsionnogo zondirovaniia zemli [Assessment of the

influence of slope mesorelief on the spatial variability of soil properties and vegetation cover characteristics based on remote sensing data]. *Issledovanie Zemli iz kosmosa — Study of Earth from cosmos,* 3, 66–74 [in Russian].

8 Terekhin, E.A. (2019). Sezonnaia dinamika proektivnogo pokrytiia rastitelnosti agroekosistem na osnove spektralnoi sputnikovoi informatsii [Seasonal dynamics of projective cover of vegetation of agroecosystems based on spectral satellite information]. *Sovremennye problemy distantsionnogo zondirovaniia Zemli iz kosmosa — Modern problems of remote sensing of the Earth from space, 16* (4), 111–123 [in Russian].

9 Leedzhieva, N.Ts., Ulanova, S.S., & Fedorova, N.L. (2012). Opyt primeneniia indeksa vegetatsii (NDVI) dlia opredeleniia biologicheskoi produktivnosti fitotsenozov aridnoi zony na primere regiona chernye zemli [Experience in applying the vegetation index (NDVI) to determine the biological productivity of arid zone phytocenoses on the example of the Black Lands region]. *Izvestiia Saratovskogo universiteta — Proceeding of Saratov University. Series chemistry. Biology. Ecology, 12* (2) [in Russian].

10 Gulianov, Yu.A. (2019). Monitoring fitometricheskikh parametrov s ispolzovaniem innovatsionnykh metodov skanirovaniia posevov [Monitoring of phytometric parameters using innovative crop scanning methods]. *Tavricheskii vestnik agrarnoi nauki — Tauric proceeding of agrarian science,* 3(19), 64–76 [in Russian]. https://doi.org/10.33952/2542-0720-2019-3-19-64-76

11 Shevyrnogov, A.P., Larko, A.A., Vysotckaia, G.S., & Somova, L.A. (2019). Opredelenie granits biomov na territorii Evrazii po dinamike dispersii NDVI na osnove sputnikovogo monitoringa [Determination of biome boundaries in Eurasia by NDVI dispersion dynamics based on satellite monitoring]. *Uspekhi sovremennogo estestvoznaniia — Advances in modern natural science,* 1, 123–128 [in Russian].

12 Han, J.C., Huang, Y., Zhang, H., & Wu, X. (2019). Characterization of elevation and land cover dependent trends of NDVI variations in the Hexi region, northwest China. *Journal of Environmental Management, 232*; 1037–1048.

13 Zolotokrylin, A.N., Titkova, T.B., Cherenkova, E.A., & Vinogradova, V.V. (2016). Dinamika letnego uvlazhneniia i biofizicheskikh parametrov aridnykh pastbishch Evropeiskoi chasti Rossii v 2000–2014 gg. [Dynamics of summer moistening and biophysical parameters of arid pastures of the European part of Russia in 2000–2014.]. *Aridnye ekosistemy — Arid ecosystems, 22*(1(66), 5–10 [in Russian].

14 Telnova, N.O. (2017). Vyiavlenie i kartografirovanie mnogoletnikh trendov NDVI dlia otsenki vklada izmenenii klimata v dinamiku biologicheskoi produktivnosti agroekosistem lesostepnoi i stepnoi zon Severnoi Evrazii [Identification and mapping of multi-year NDVI trends to assess the contribution of climate change to the dynamics of biological productivity of agroecosystems in the forest-steppe and steppe zones of Northern Eurasia]. *Sovremennye problemy distantsionnogo zondirovaniia Zemli iz kosmosa — Modern problems of remote sensing of the Earth from space, 14* (6), 97–107 [in Russian].

15 Gao, Y., Huang, J., Li, S., & Li, Sh. (2012). Spatial pattern of non-stationarity and scale-dependent relationships between NDVI and climatic factors — A case study in Qinghai-Tibet Plateau, China. *Ecological Indicators, 20*; 170–176.

16 Zhao, Z., Gao, J., Wang, Y., Liu, J., & Li, S. (2015). Exploring spatially variable relationships between NDVI and climatic factors in a transition zone using geographically weighted regression. *Theoretical and Applied Climatology, 120*(3-4); 507–519. https://doi.org/10.1007/s00704-014-1188-x

17 Zhukov, A.V., Kunakh, O.N., Zadorozhnaia, G.A., & Andrusevich, E.V. (2013). Landshaftnaia ekologiia kak osnova prostranstvennogo analiza produktivnosti agrotsenozov [Landscape ecology as a basis for spatial analysis of agrocenosis productivity]. *Ecology and noospherology, 24*(1–2), 68–80 [in Russian].

18 Gopp, N.V. (2021). Tsifrovoe kartografirovanie prostranstvennoi izmenchivosti parametrov pochv i rastitelnosti na yugovostoke Zapadnoi Sibiri [Digital mapping of spatial variability of soil and vegetation parameters in the south-east of Western Siberia]. *Doctor's thesis*. Novosibirsk: Institut pochvovedeniia i agrokhimii Sibirskogo otdeleniia Rossiiskoi akademii nauk [in Russian].

19 Nikolaev, V.A. (1999). *Landshafty aziatskikh stepei [Landscapes of Asian steppes]*. Moscow: Moskovskii gosudarstvennyi universitet [in Russian].

20 Khoroshev, A.V., Tkach, K.A., & Murtazina, D.U. (2018). Vliianie landshaftnykh uslovii na urozhainost zernovykh kultur v stepnoi zone Severnogo Kazakhstana [Influence of landscape conditions on the yield of grain crops in the steppe zone of Northern Kazakhstan]. *Vestnik Moskovskogo universiteta. Seriia 5. Geografiia — Bulletin of Moscow University. Series 5. Geography,* 3; 62–69 [in Russian].

21 Pogoda i klimat [Weather and climate]. Retrieved from http://www.pogodaiklimat.ru [in Russian].

22 Khokonova, M.B. & Adzhieva, A.A. (2016). Zakonomernosti naliva i prirosta sukhoi biomassy yarovoi pshenitsy [Regularities of the filling and dry biomass growth of spring wheat]. *Izvestiia Kabardino-Balkarskogo gosudarstvennogo agrarnogo universiteta imeni V.M. Kokova — Proceedings of Kabardino-Balkarian State Agrarian University named after V.M. Kokov,* 6 [in Russian].

23 Eroshenko, F.V., Bartalev, S.A., & Lapenko, N.G. (2018). Vozmozhnosti distantsionnoi otsenki sostoianiia i stepeni degradattsii prirodnykh kormovykh ugodii [Opportunities of remote sensing of the state and degree of degradation of natural fodder lands]. *Sovremennye problemy distantsionnogo zondirovaniia Zemli iz kosmosa — Modern problems of remote sensing of the Earth from space, 15* (7); 53–66 [in Russian].

Information about authors

Kiryanov-Gref, Fedor Konstantinovich — Bachelor of geography, Lomonosov Moscow State University, Moscow, Russian Federation; kir_gref@mail.ru;

Khoroshev, Alexander Vladimirovich — Doctor of geographical sciences, Docent of Department of Physical Geography and Landscapes, Lomonosov Moscow State University, Moscow, Russian Federation, avkh1970@yandex.ru;

Anatskaya, Ksenia Anatoljevna — Institute of Geography and Nature Management, Astana International Scientific Complex, Astana, Kazakhstan; anat_ka@yandex.ru.