Assessment of vegetation cover on abandoned agricultural forest-steppe lands using multivariate analysis of their spectral response

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Abstract. It is crucial for all the regions including the forest-steppe zone that the vegetation cover on abandoned agricultural lands is thoroughly studied. This paper reviews some challenges of abandoned agricultural lands, which can be used as the basis for the real-time analysis of vegetation dynamics. The study aims to assess the capacity of automatic identification of forest stands established on abandoned agricultural lands through multivariate analysis of their spectral response. Based on the analysis of spectral reflective characteristics of abandoned agricultural lands from Landsat OLI data, it was found out that the reflective features of abandoned areas with deciduous, coniferous, and mixed forest stands differ significantly in the infrared band. It has been proposed to recognize abandoned agricultural lands with deciduous and coniferous forest stands through discriminant analysis of their reflective characteristics. It has been proved that reflectance in the red and infrared bands can be used to automatically detect abandoned agricultural lands with deciduous and coniferous stands. It is more challenging to identify abandoned areas with mixed forest stands.

1. Introduction
Abandoned agricultural lands are former plough lands withdrawn from agricultural use for one or more seasons. It is important to study the condition of vegetation on abandoned agricultural lands to get an idea of the particular features of the related successions [1], which act as the growth indicators for vegetation. It is essential to analyse the condition of abandoned lands in order to monitor the changes occurring in the environment [2, 3, 4]. Two decades ago tree vegetation began emerging on abandoned agricultural lands of the forest-steppe zone, including the territory of the Central Chernozem Region of Russia [5]. In this regard, one of the primary tasks for the study of successions on abandoned agricultural lands is to define the types of the established forest stands: deciduous, coniferous, or mixed.

Multi-spectral satellite images have been extensively used in the past two decades to identify and assess the condition of abandoned agricultural lands [6-9]. Deciduous and coniferous tree species can be visually recognised in quite an efficient way when analysing multi-spectral satellite data in combinations with visible and infrared bands. However, taking into consideration that the areas of abandoned agricultural lands are numerous and in many cases, they are scattered unevenly, it is necessary to develop computer-aided methods to determine their characteristics [10-12]. The reflectance features of abandoned areas can theoretically act as independent variables for indication of related forest stand types. This is due to the impact made by the species composition on the spectral
response of tree vegetation [13-15]. However, solving such problems requires multidimensional analysis methods, which take into account the information content of each analysed spectral feature and use their combinations to determine the estimated parameters of abandoned agricultural lands.

Discriminant analysis is one of the methods of multivariate statistical analysis, which can be used to categorise certain object classes based on their characteristics. In our case, such features can include spectral reflectance characteristics of abandoned agricultural lands measured using satellite data. The discriminant analysis method makes it possible to take into account particular reflectance features, which can be used to map out types of agricultural areas or vegetation cover [16].

The study aims to assess the possibilities of automated identification of forest stand types present on abandoned agricultural lands (deciduous, coniferous, and mixed forests) based on discriminant analysis of their reflectance.

2. Materials and methods

The study was carried out in the forest-steppe zone of the Central Chernozem Region of Russian Federation. The abandoned agricultural lands being analysed were located in Belgorod, Oryol, Voronezh, Lipetsk, Tambov, and Kursk Oblasts (figure 1).

![Figure 1. Location of the study area.](image)

We selected the agricultural areas to be analysed in such a way as to have a representative sampling of the main types of forest stands being present on abandoned forest-steppe agricultural lands: deciduous, coniferous, and mixed forests. For experimental studies, we identified the abandoned areas using the analysis of ultra-high spatial resolution satellite images obtained in the period from 2018 to 2019 from open access resources, mainly Google Earth. We identified the abandoned agricultural lands based on their features subject to image structural and textural specific characteristics, which are formed by the vegetation cover, and distinguished them from the cultivated land. The types of forest stand on abandoned agricultural lands were assessed on the basis of the same images used to identify them. In order to analyse the types of forest stands, we additionally used the Landsat OLI multi-spectral satellite data for 2018 with a spatial resolution of 30 m (figure 2).
Figure 2. Examples of abandoned lands with various types of forest on Landsat 8 OLI imagery (Band synthesis 7-6-4): a – Deciduous, b – Coniferous, c – Mixed.

This data type makes it possible to visually distinguish the abandoned agricultural lands with deciduous, coniferous, and mixed species. We identified and studied 261 plots of abandoned agricultural lands with a total area of 8,656.8 hectares (table 1) and an average area of 33.2 hectares. For the plots being analysed, we used GIS to create a vector layer with their contours. It was needed at a later stage to calculate the spectral reflectance of abandoned agricultural lands.

| Forest types on abandoned lands | Mean area, ha | Number of objects | Total area, ha |
|--------------------------------|--------------|-------------------|---------------|
| Coniferous                     | 28.2         | 56                | 1581.1        |
| Mixed                          | 47.2         | 59                | 2786.5        |
| Deciduous                      | 29.4         | 146               | 4289.2        |
| Average                        | 33.2         | 261               | 8656.8        |

The spectral reflectance of abandoned agricultural lands was assessed using Landsat 8 OLI satellite data obtained in August 2018. For the analysis, we used three Landsat 8 images (Path 177). The images were taken on the same day August 24, 2018. In the WRS-2 (World Reference System-2) used to locate Landsat images on the Earth’s surface, the images were arranged in the following Rows: 23, 24, and 25. The Landsat OLI data include 6 main bands. Since Landsat OLI scenes are taken regularly, it is possible to use them for the complete coverage of the study area with the images close together by date.

We selected the images to be used to assess reflectance characteristics assuming that they should be obtained simultaneously during the active vegetation period in order to minimise phenological differences between the vegetation of abandoned agricultural lands located in different parts of the area under study. It was required that images should include no clouds. August in the forest-steppe within the Central Chernozem Region of Russia is the least cloudy month, and it is the only period when we managed to collect cloudless satellite data. For the analysis, we selected the abandoned
agricultural lands covered by the relevant satellite images. All Landsat images were atmospherically and radiometrically calibrated and converted to reflectance coefficients.

For each area of agricultural land, we used zonal statistics to calculate reflectance for the following six spectral ranges: blue, green, red, near-infrared, and two mid-infrared. We calculated the spectral parameter values averaged within the vector outlines of abandoned agricultural lands. The listed reflectance features acted as independent input variables for discriminant analysis.

At the first stage of statistical analysis, we calculated and compared the statistical parameters of each reflectance characteristic for the areas of abandoned agricultural lands with deciduous, coniferous, and mixed forest stands. Using the analysis-of-variance method, we assessed the significance of differences in specific spectral features for abandoned areas with different types of forest stands. According to the level of difference significance, we preliminarily identified the reflectance features, which are most informative for the recognition of deciduous, coniferous, or mixed forest stands growing on abandoned agricultural lands.

At the main stage, we analysed the contribution made by diverse range reflectance to the classification of abandoned areas by forest stand types. As part of this stage, we identified the most informative spectral characteristics to automatically recognise types of forest stands being present on abandoned agricultural lands. An assessment was carried out using stepwise discriminant analysis followed by its sequential incorporation in the model of spectral features, which significantly facilitated the classification of abandoned agricultural lands different in the type of the established forest stands. Then we calculated the functions, which can be used to automatically identify the abandoned agricultural lands with deciduous, coniferous, or mixed forest stands. To assess the efficiency of the functions, all selected areas of abandoned agricultural lands were divided into training and test samples. To estimate accuracy, we used the percentage of correctly recognised types of abandoned agricultural lands.

3. Results and Discussion

The analysis of spectral reflectance properties has shown that they have average quantitative differences in all ranges of abandoned agricultural lands with different types of forest stands (table 2), but their values vary. As a result of the variance analysis, it was revealed that in the blue band there are statistically insignificant differences among the areas of abandoned agricultural lands with different types of forest stands. In the green and red bands, there are statistically significant differences between abandoned areas with coniferous tree species and other types of abandoned agricultural lands. In the near-infrared range, there are statistically significant differences between all types of abandoned agricultural lands, but they are most evident in the SWIR1 band (1.56-1.66 μm). The obtained results preliminary indicate that the reflectance of this range (Landsat OLI band 6) should be the most informative for the classification of abandoned agricultural lands by types of forest stands.

Table 2. Average Landsat OLI reflectance values for abandoned agricultural lands with different forest stand types.

| Type of forest stand | Band 2  | Band 3  | Band 4  | Band 5  | Band 6  | Band 7  |
|----------------------|---------|---------|---------|---------|---------|---------|
| Deciduous            | 0.095   | 0.081   | 0.063   | 0.275   | 0.190   | 0.095   |
| Mixed                | 0.097   | 0.080   | 0.063   | 0.256   | 0.177   | 0.092   |
| Coniferous           | 0.096   | 0.077   | 0.058   | 0.241   | 0.140   | 0.072   |

Thus, due to its low information content, the blue spectral reflectance (band 2) was excluded from further analysis. In other words, 5 variables, which included the reflectance of abandoned agricultural lands in green, red, near-infrared, and two SWIR bands, were directly involved in the discriminant analysis.
Differences in the spectral response of abandoned agricultural lands with different types of forest stands were clearly defined in the graphical analysis of reflectance properties for abandoned lands with deciduous, coniferous, and mixed forest stands (figure 3).

![Graphical analysis of reflectance properties](image)

**Figure 3.** Spectral response of abandoned agricultural lands with deciduous (1), mixed (2), and coniferous (3) forest stands.

Based on stepwise discriminant analysis results, the following two variables were included in the model for recognition of abandoned agricultural lands by types of forest stands: SWIR1 and Red-band reflectance (Table 3). The remaining spectral reflectance turned out to contribute much less to the type classification of abandoned agricultural lands. With various options, the SWIR1 (1.56 – 1.66 µm) reflectance values were always included in the model at the first stage, which confirms their maximum efficiency for automated recognition of abandoned areas with deciduous, coniferous, and mixed forest stands.

| Variable        | Stage | F     | p-level | Number of variables in model |
|-----------------|-------|-------|---------|-----------------------------|
| SWIR1 reflectance | 1     | 50.02 | 0.000   | 1                           |
| RED reflectance  | 2     | 49.18 | 0.000   | 2                           |

Table 3. Results of the reflectance stepwise discriminant analysis of abandoned agricultural lands.

Based on the results of the discriminant analysis, we calculated coefficients of classification functions (Table 4), each being a linear equation, which makes it possible to calculate the classification weight for each type of abandoned agricultural land. Thereupon, the abandoned agricultural lands being analysed will automatically fall into specific types: deciduous, coniferous, or mixed forest stands.

Classification functions are calculated for each type of abandoned agricultural land. In our case, 3 functions were calculated. The first function was calculated for abandoned lands with deciduous species. The second function was calculated for abandoned agricultural land with coniferous species. The third function was calculated for abandoned lands with a mixed forest stand. The independent variables in the functions were the spectral-reflective features of the 4th and 6th bands of the Landsat OLI sensor. For each abandoned land being analysed, three classification weights are calculated using
the functions. The abandoned agricultural land will automatically belong to the type for which the classification weight was the highest. The reflectance values of the most informative ranges, calculated from the Landsat OLI data, must be known for each abandoned land before image processing.

Table 4. Linear functions coefficients for calculation of classification weights for abandoned agricultural lands with deciduous, coniferous and mixed forest stands.

| Variable | Abandoned agricultural land with various forest stands |
|----------|----------------------------------------------------|
|          | Coniferous            | Mixed          | Deciduous          |
| SWIR1 (x₁) | -242.1          | -28.8          | 44.3           |
| RED(x₂)      | 1552.2          | 1006.4         | 812.6          |
| Constant     | -29.8           | -30.7          | -30.8          |

The efficiency of the calculated functions varies significantly for the identification of abandoned agricultural lands with different types of forest stands. For deciduous forest stands, it is quite high and amounts to 98.8% for the training sample and 96.7% for the test sample (table 5). It is typical for coniferous forest stands to have a lower accuracy, which was 83.3% and 70%, respectively. The main problem is to identify abandoned agricultural lands with mixed forest stands. When being recognised, most of them were classified as abandoned agricultural lands with the deciduous tree species. Thus, the main limitation for the calculated function is that it is problematic to classify these types of arable agricultural land.

Table 5. Accuracy of abandoned lands recognition with various forest stand types.

| Forest stand type | Recognition accuracy (%) |
|-------------------|--------------------------|
|                   | Training sample | Test sample  |
| Deciduous         | 98.8            | 96.7        |
| Coniferous        | 83.3            | 70.0        |
| Mixed             | 17.2            | 10.0        |
| Total             | 79.2            | 68.5        |

The reason for this limitation is in the complex nature of spectral response from abandoned lands with mixed forest stands. It is formed by the deciduous and coniferous forest stands being present on abandoned agricultural lands, as well as by extensive grasslands. However, it is not possible to take into complete account their contribution to the reflectance characteristics of abandoned areas when developing a training sample.

The calculated classification functions can be used in GIS techniques to automatically identify abandoned agricultural lands with coniferous and deciduous forest stands in the forest-steppe zone. The proposed method can be applied to the analysis of abandoned agricultural lands, typical for the forest-steppe zone since it takes into account the regional features of the spectral response of abandoned lands. They are determined by the species composition of the forests growing on abandoned agricultural lands of this natural zone. The proposed approach provides for the use of a vector layer for all analysed areas of abandoned agricultural lands with the known reflectance in the red and SWIR ranges during August.

4. Conclusion
Forest stand types established on abandoned agricultural lands affect their spectral response. It is found that deciduous-based abandoned agricultural lands are characterised by higher reflectance in the visible and near-infrared spectral ranges, as compared to abandoned agricultural lands with coniferous and mixed forest stands. In the infrared spectral range, statistically significant differences are reported to be recognised among abandoned agricultural lands with deciduous, coniferous, and mixed forest stands. The technique using discriminant analysis of spectral reflectance is proposed for automated
recognition of abandoned agricultural lands. It is the SWIR reflectance features that make the maximum contribution to the classification of abandoned areas with deciduous and coniferous forest stands. The most problematic is to identify abandoned agricultural lands with mixed forest stands. During automated recognition, this type of abandoned area most often falls under the category of abandoned agricultural lands with deciduous forest stands.

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References
[1] Lisetskii F N, Poletaev A O, Terekhin E A and Marinina O A 2021 IOP Conference Series: Earth and Environmental Science 817 012061
[2] Kurbanov E A, Vorobyev O N, Gubayev A V, Leznin S A and Nezamayev S A 2010 Vestnik Povolzhskogo gosudarstvennogo tehnologicheskogo universiteta 2 14–20
[3] Levykin S V, Chibilev A A, Kazachkov G V, Yakovlev I G and Grudinin D A 2013 Stepnoy Byulleten 37 5–8
[4] Moskalenko S V and Bobrovsky M V 2012 Izvestiya Samarskogo nauchnogo tsentra RAN 14 1332–1335
[5] Terekhin E A 2019 Sovremennye Problemy Distantsiionnogo Zondirovaniya Zemli iz Kosmosa 16 180–93
[6] Levers C, Schneider M, Prischepov A V, Estel S and Kueemmerle T 2018 Sci. Total Environ. 644 pp 95–111
[7] Goga T et al. 2019 Remote Sens. 11 2759
[8] Terekhin E A 2021 Sovremennye Problemy Distantsiionnogo Zondirovaniya Zemli iz Kosmosa 18 pp 169–81
[9] Savin I, Prudnikova E, Chendev Y, Bek A, Kucher D and Dokukin P 2021 Remote Sens. 13 2411
[10] Prischepov A V, Radeloff V C, Dubinin M and Alcantara C 2012 Remote Sens. Environ. 126 195–209
[11] Yin H, Prischepov A V, Kueemmerle T, Bleyhl B, Buchner J and Radeloff V C 2018 Remote Sens. Environ. 210 12–24
[12] Yoon H and Kim S 2020 ISPRS J. Photogram. and Remote Sens. 166 201–12
[13] Zhirin V M, Knayzeva S V and Eydilina S P 2014 Contemp. Probl. Ecol. 7 788–96
[14] Zharko V O and Bartalev S A 2014 Sovremennye Problemy Distantsiionnogo Zondirovaniya Zemli iz Kosmosa 11 159–70
[15] Kurbanov E A, Vorobev O N, Menshikov S A and Smirnova L N 2018 Sovremennye Problemy Distantsiionnogo Zondirovaniya Zemli iz Kosmosa 15 154–66
[16] Terekhin E A 2019 Comput. Optics 43 4 pp 2–8