Using spectral indices for interpretation of plant residues under different tillage systems

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Abstract. Intensification of agriculture leads to development and implementation of new soil conservation technologies that reduce degradation processes, as well as the development of methods for monitoring and controlling these technologies. Spectral indexes method as one of the methods of remote sensing is one of the most modern methods for solving this problem. This research was conducted on three production fields located in the territory of the Budenovsky district of the Stavropol territory, where plowing with the layer turnover and no-till technology were used. Aim of this research is analysis of the possibility of using 8 spectral indices to identify different types of soil cultivation. The study found that the most informative differences between tillage systems are provided by NDTI, STI and NDI7, which use the SWIR 2 spectral range for calculations. In addition, the classification of objects based on these indexes by the K-means method gives the highest accuracy.

1. Introduction

One of the most important tasks of modern agricultural science is to find a balance between the intensification of land use and at the same time the preservation of soil fertility close to its natural state. In many regions of the world, various soil treatment technologies are actively used to reduce the anthropogenic effect. One of the most widely used technologies for rational land use is no-till, also called direct seeding [1, 2]. According to the Food and Agriculture Organization of the United Nations (FAO) [3], the principal features of no-till are: lack of physical impact on the soil by agricultural machinery and tools, preservation of crop residues on the surface of soil, use of crop rotation. In no-till many scientists assign a special role to the preservation of crop residues on the soil surface[4, 5]. Crop residues contribute to the creation of their own microclimate on the soil surface, which support to the preservation of soil moisture, improves the agrochemical and agrophysical properties of the soil [6]. In addition, crop residues significantly change the appearance of fields, creating a special surface characteristic of direct seeding and thus allow the use of remote sensing to explore the technology of no-till. The use of aerospace methods in the case of determining crop residues can solve two important problems:

1) Identification of farms using no-till for accounting and solving production problems at the district and regional levels

2) Monitoring and quantitative assessment the state of crop residues for crop residue management

One of the most common methods of processing and analyzing remote sensing data is the spectral
indices. To date, several spectral indices are used for accounting and analyzing the state of crop residues. The aim of this research is to analyze the possibility of using spectral indices to interpretate crop residues data for classification and analysis of the state of objects.

2. Materials and methods

The research area is located in the territory of the Arkhangelsky agricultural production cooperative and neighboring farm in the Budenovsky district of the Stavropol territory, in the watershed of the Kuma River and the Gorky Balka river. The Arkhangelsky cooperative has been using no-till for more than 7 years, and the neighboring farm uses the system of soil treatment with soil layer turnover traditional for this region. According to the soil map of the North Caucasus research Institute of agriculture and the Unified state register of soil resources, farm soils belong to temno-kashtanovye (Haplic Kastanozems Chromic WRB 2006).

The research area is located in an arid agro-climatic region, which is characterized by a high degree of continentality of the climate. According to long-term climate observations, the average annual temperature is +10.7°C, the minimum is in January and is -2.3°C, maximum is in July +24.5°C. Average annual rainfall is 460 mm. The main vegetation period is 189 days from 13.04 to 18.10, average precipitation during the vegetation period is 324 mm [7]. During field research in August-September 2019, 3 key fields were selected (table 1). The choice of key fields is related to the features of no-till. If the no till technology is followed correctly, the soil is never left bare, and to correctly decipher the data it is necessary to know what reflective properties the open soil has and what values of spectral indices it will take. It is not always possible to remove all plant residues from the soil surface after harvesting using traditional technology, and to decipher no-till it is important to determine the difference between the reflectivity of crop residues left after harvesting using traditional technology and using no-till.

Table 1. Properties of fields to research

| Properties of key fields | Coordinates | Area, ha |
|-------------------------|-------------|---------|
| Field after harvesting winter wheat using no-till | 44° 32.842’ northern latitude 44° 10.547’ eastern longitude | 161 |
| Field after harvesting winter wheat using traditional technology | 44° 32.000’ northern latitude 44° 9.935’ eastern longitude | 109 |
| Field after the harvest of mustard in the traditional technology (bare soil) | 44° 31.875’ northern latitude 44° 10.467’ eastern longitude | 42.5 |

There are two similar approaches in the literature on the determination of crop residues. The first approach is to determine the reflectivity of crop residues by field or laboratory methods using specialized equipment such as spectrometers, thermal imagers, determination of ranges of the electromagnetic spectrum in which crop residues differ most from other surfaces, such as bare soil, living vegetation and further application of hyperspectral or multispectral data of remote sensing to determine the spatial distribution of plant residues on the surface [8,9]. The second approach is to determine the amount or area of vegetation cover per unit area in the field and further build and select mathematical models that include field measurements and remote sensing data that best reflect the relationship between the state of crop residues and their reflectivity in different ranges of the electromagnetic spectrum [10,11]. All researches related to the decryption of plant residues are combined by the use of various spectral indices. Based on the literature, 8 most common spectral indices were
selected, calculated from Sentinel 2 and Landsat data, used for determining crop residues (Table 2).

| Index | Formula | Reference |
|-------|---------|-----------|
| CRC1  | SWIR1 − Blue | [12–14] |
|       | SWIR + Blue |           |
| MCRC  | SWIR1 + Green | [12–14] |
|       | SWIR1 − RED  |           |
| NDSVI | SWIR1 + RED  | [15,16]  |
|       | SWIR2 − Red  |           |
| SRNDI | SWIR2 + Red  | [16]      |
|       | NIR − SWIR2  |           |
| NDI7  | NIR + SWIR2  | [17]      |
|       | NIR − SWIR1  |           |
| NDI5  | NIR + SWIR1  |           |
| NDTI  | SWIR1 − SWIR2| [18]      |
|       | SWIR1 + SWIR2|           |
| STI   | SWIR1       | [18]      |

Processing and analysis of remote sensing data was carried out using Google earth engine (GEE) [19]—cloud platform for processing and analyzing geospatial data. GEE provides collections of remote sensing data of various processing levels, as well as a large Toolkit for processing, analyzing and visualizing this data. In this research, 4 scenes of Sentinel 2 satellite images of the processing level 2A system were selected, in the time period from July 15 to September 15, 2019. The time period from mid-July to mid-September is related to the period of harvesting crops in this region. Images of spectral indexes were calculated for each scene, polygons of key fields were built, and points were randomly added within each polygon (10 for each polygon), where spectral index values for each scene were extracted. To evaluate the reflective properties of surfaces according to Sentinel-2 data, spectral curves were plotted. The K-means algorithm was used for classification, and further to quantify the applicability of spectral indices for surface classification, the classification accuracy was calculated for each index. All statistical processing and visualization of data was performed in RStudio.

3. Results and Discussion
As a result of the analysis of reflectivity curves, it was found that the bare surface of the soil in the dynamics from July 19 to September 12 does not have significant fluctuations (Figure 1). The reflectivity curve for no-till on July 19 has values in SWIR1 higher than traditional processing and SWIR2 lower than traditional processing. August 13 the reflectivity for no-till has values higher than for traditional tillage in all spectra except SWIR2, in SWIR2 the values are approximately the same. On August 18, in all the researched ranges, the values for no-till fall relative to the values for traditional tillage, and on September 12, there are differences between the reflectivity of traditional tillage and no-till only in NIR.
Figure 1. Reflectivity curves of key fields

As a result of processing and analysis of multispectral data, graphs of the dynamics of the values of the studied spectral indices for three key fields were constructed (Figure 2). CRC1, MCRC, NDI5, NDSVI, SRNDI indexes do not provide statistically significant differences between samples over a number of time periods and, as a result, are not informative enough to identify differences between key fields. The dynamics of NDI7, NDTI, and STI values in all imputed periods has significant differences. The curve geometries for the samples for the three indexes are similar. It is important to note that the curve of dynamics of values for bare soil has practically no fluctuations in all periods, as well as the curve of dynamics for traditional technology has weak fluctuations. However, quantitatively the surface of traditional tillage has values always higher than bare soil, in all time periods, which will allow on the basis of these indices, for sufficiently qualitatively dynamical separation of bare soil from crop residues after harvesting crops when using traditional technology. The values of the spectral indices NDI7, NDTI, STI for crop residues in the field where direct seeding technology is used from the beginning of observations until August 12 have higher values than for crop residues using traditional tillage and bare soil. Further, in the period from August 12 to August 18, there is a drop in values, and until the end of the observation period, the values are consistently lower than those of crop residues with traditional tillage. We attribute this drop to a period of high temperatures (a period with average temperatures of about 28° C) from August 15 to 25, which led to over-heating of crop residues.

Table 3. Percentage of correct classifications when using the K-means algorithm

| Index  | CRC1 | STI | MCRC | NDI5 |
|--------|------|-----|------|------|
| percentage of correct classifications | 93.3 | 99.0 | 63.3 | 83.3 |

| Index  | NDI7 | NDSVI | NDTI | SRNDI |
|--------|------|-------|------|-------|
| percentage of correct classifications | 99.0 | 86.7 | 99.0 | 66.7 |
Figure 2. Dynamics of spectral indices and climate indicators over time

In addition to visual assessment of the dynamics of spectral indices by graphs, the possibility of using each of the indices for surface classification was also evaluated. Using the K-means algorithm, the data for each spectral index was divided into 3 clusters, and the accuracy of cluster selection was analyzed (Table 3). Analysis of the classification results shows that the most accurate classification is given by the spectral indices STI, NDTI, NDI7. This suggests that these indexes are best suited for surface classification.

4. Conclusion
In the course of this research, it was found that the most significant informative differences between bare soil and soil covered with crop residues when using different tillage technologies are given by the NDTI, STI and NDI7 indices. A special feature of these indexes is the use of the SWIR 2 range in calculations. These indexes allow us to detect the difference between surfaces at a statistically reliable level in the post-harvest period. In addition, changes in the dynamics for the no-till sample allow us to draw conclusions about changes in crop residues due to season and the influence of climate factors.
Cluster analysis using the K-means method allowed us to evaluate the possibility of using spectral indices for surface classification. It was found that the NDTI, STI, and NDI7 indexes have the largest number of correct classifications, this confirms the conclusion that it is possible to use these indices in the interpretation of different soil treatment systems and monitoring the state of crop residues during no-till. The materials presented in this research form the basis for further study of plant remains using aerospace methods.

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