E3S Web of Conferences **539**, 02035 (2024) https://doi.org/10.1051/e3sconf/202453902035
RSE-III-2024

Assessment of the State of Plant Biomass Based on the Integration of Multispectral Sensors of Optical and Radio Ranges

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Abstract. One of the main tasks of using remote sensing in agriculture for precision farming purposes is to identify management zones or management zones within which the timing and parameters of agrotechnical measures differ significantly. To clarify the boundaries of these zones, it is proposed to use jointly data on soil moisture (electrical conductivity) and the normalized plant index (NDVI) in a field of about 70 hectares. Based on spatial variations of humidity data obtained using a bistatic radar system and electrical conductivity obtained using electromagnetic scanning, as well as NDVI indices obtained using multispectral cameras, maps of the spatial distribution of these parameters are constructed. To determine the control zones, a fuzzy clustering algorithm was used, three target classes for assessing the state of plant biomass with restrictions on the percentage of moisture in the soil were identified. An analysis of 813 points of the soil surface was carried out with reference to geographical coordinates, the elements of the array were assigned to one of the target classes corresponding to one of the three control zones. The results of the analysis of arrays formed by classes allow us to conclude that it is possible to use fuzzy clustering to determine the boundaries of control zones in conditions of significant heterogeneity of the studied fields in terms of physico-chemical properties and relief.

1 Introduction

Remote sensing data is currently considered as the most operational and objective (independent) source of information on the state of agricultural lands and vegetation on them [1]. The distribution of spectral reflectivity across zones [2] is used to judge the state of vegetation and soil cover and the possibility of using multi-zone images to study the spatial heterogeneity of the surface [3-4].

To conduct studies of vegetation indices and soil moisture, space optical and IR systems of low (AVHRR, NOAA, MODIS EOS/Terra, etc.) and medium resolution (ASTER and TM/ETM) are used [5-6], and studies of soil moisture are possible to a depth of 0.4 m in

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homogeneous soils with gradations of 2-4% (with a relative margin of error of about 12%). The disadvantage of this type of satellite imagery is the low resolution of radiometric images [7-8]. Much greater accuracy, resolution and efficiency can be achieved by using a multispectral camera and a bistatic radar system located on two unmanned aerial vehicles (UAVs) together to obtain the distribution of NDVI indices and soil moisture.

The purpose of the study is to confirm the possibility of assessing the state of plant biomass based on the integration of multispectral sensors of optical and radio ranges in the course of solving problems of ensuring the completeness of the implementation of plant biopotential and determining the quality of agrotechnical measures at various stages of the life cycle of cultivated crops. The main task of the integration is to create schemes for the effective joint use of vegetation indices and physico-chemical properties of the soil (for example, humidity, electrical conductivity, etc.) to determine control zones in the implementation of precision farming technology. The need for data aggregation is due to the fact that using only vegetation indices does not always allow to fully assess the state of plant biomass, for a more complete semantic content of the images, field and laboratory soil studies are required.

The use of a bistatic radar system to quickly obtain information about the physico-chemical properties of the soil with an accuracy of ± 1% makes it possible to replace long-term and time-consuming spot laboratory studies. The accuracy of determining the optical range data, spatial resolution and vegetation indices used is determined by the parameters of hyper- and multispectral cameras. Spatial errors of radio and optical band data depend on the accuracy of the location of satellite navigation receivers and spatial data processing algorithms.

2 Materials and methods

Assessment of the state of biomass is carried out by step-by-step solution of the following tasks:

- Remote assessment of the state of biomass from images of a multispectral camera located on a mobile carrier (for example, an unmanned aerial vehicle UAV) using vegetation indices. The advantage of this approach is the absence of dependence on clouds, higher efficiency (relative to satellite images), and the ability to vary the spatial resolution of the data by changing the speed and altitude of flight.
- In case of deviation of the vegetation indices from the expected values, the analysis of the established zones is carried out using a probing bistatic radar system in the radio range (at a frequency of 469 MHz).
- Based on the data received in the radio range, segmentation of higher spatial resolution data is carried out.
- Compilation of an n−dimensional feature space and ternary fuzzy clustering of the resulting dataset.

Let's give a set of observations X={x_1,..., x_n }, while under each x_i we will understand vector and multidimensional scalar values of parameters characterizing the type of plants under study. The assessment uses parameters reflecting the state of biomass (vegetation indices obtained using optical measurements with a multispectral camera) and soil condition (for example, humidity and electrical conductivity obtained using a bistatic radar system). There are three target classes for assessing the state of biomass: natural plant development (optimal), oppression by lack of parameter values (lack) and oppression by excess of parameter values (overbundance). The limitations are the permissible numerical ranges of the normalized vegetation difference index (NDVI) used and the percentage of moisture in the soil measured through the Brewster angle [9]. It is necessary that the data sets of the optical and radio bands have equal power.

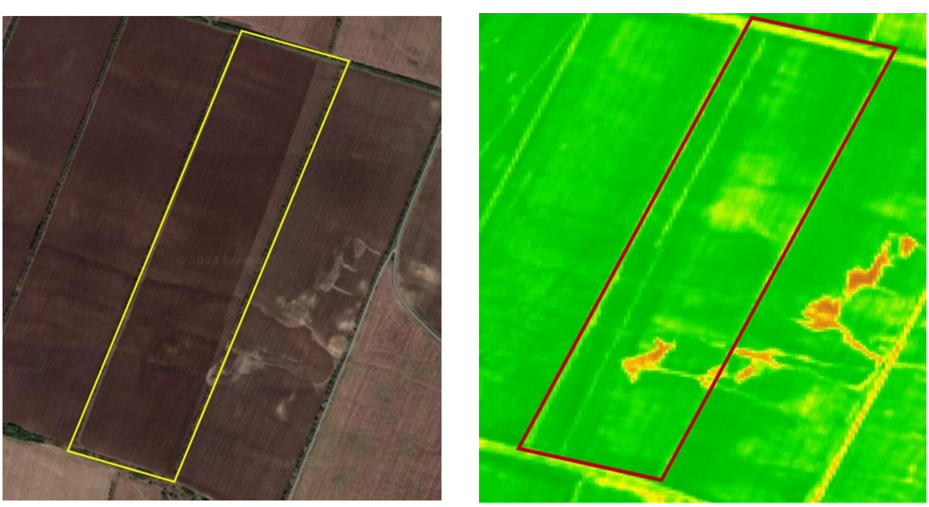
In the case when the spatial resolutions of the optical and radio band data coincide (1 pixel of the optical image to 1 indicator of the bistatic radar system), segmentation is not required. If the spatial resolution of the optical image is higher than the spatial resolution of the bistatic radar system, then as a result of calculations we obtain the number of pixels that should correspond to one indication of the bistatic system. In the case when the resolution of the optical image is lower, the recalculation and formation of the radio band feature space is carried out.

To compile an n-dimensional space and ternary fuzzy clustering of the resulting data set at specified starting points, the authors propose the use of a mathematical apparatus of fuzzy logic, namely fuzzy clustering [10].

3 Results and Discussion

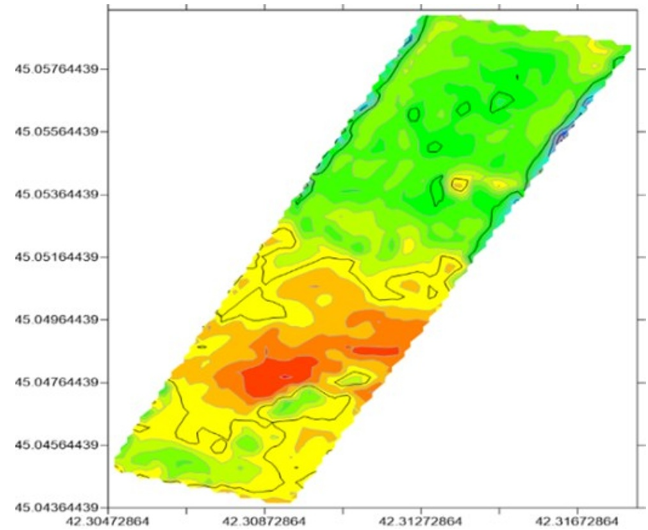
In Figure 1, and a satellite image of the test field of JSC Agroholding "Steppe" in the area of the village of Beshpagir in the Grachevsky district of the Stavropol Territory is presented. In Figure 1, b presents the results of calculating the NDVI index of the test field obtained using a multispectral camera located on the UAV. The measurements were made at a speed of 30 km/h, the interval between measurement points was 20-40 m along and 30 m across the field.

The test field is heterogeneous in terrain and NDVI. In view of this, we will analyze the field using the AEMP-14 ground device (an electromagnetic scanner for fast non-contact imaging of upper 8-meter profiles at frequencies from 2.5 to 250 kHz) and using a bistatic radar system under the same UAV flight conditions. Thus, the resolution of the "multispectral camera-bistatic radar system" system is determined, among other things, by the speed and altitude of the UAV flight. Figure 2 shows maps of the electrical conductivity and humidity of the studied area at the depth of the root zone of plants. The results of humidity mapping were obtained using the MATLAB R2020a application package. The collected electrical conductivity data was optimized using the QZond 4.7 (Android) and iSystem 4.05 (Windows PC) software.

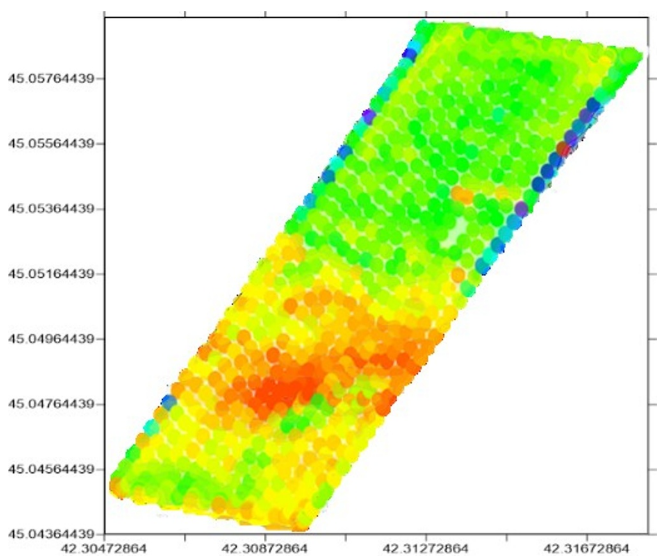


a b

Fig. 1. Studying field: satellite image (a) and NDVI map (b).



a



b

Fig. 2. Electrical conductivity (a) and humidity (b) maps of the test field.

Despite the insignificant area of the NDVI heterogeneity (Figure 1,b), the electrical conductivity and volumetric humidity at the level of the root zone of plants differ significantly in the area of the zones and in the values of the parameters.

Let's segment the data with a higher spatial resolution. After compiling the final data set, in which one point of humidity readings corresponds to one point of NDVI readings, data clustering was performed using known formulas [10]. The size of the analyzed sample was 813 measurements for optical and radio bands. b_{min}=0;10, b_{opt}=0.4;30, b_{max}=0.8;55 are selected as the starting points of cluster centers. The clustering result show in Figure 3.

The result of the fuzzy clustering algorithm is Table 1 with the definition of belonging to a selected class.

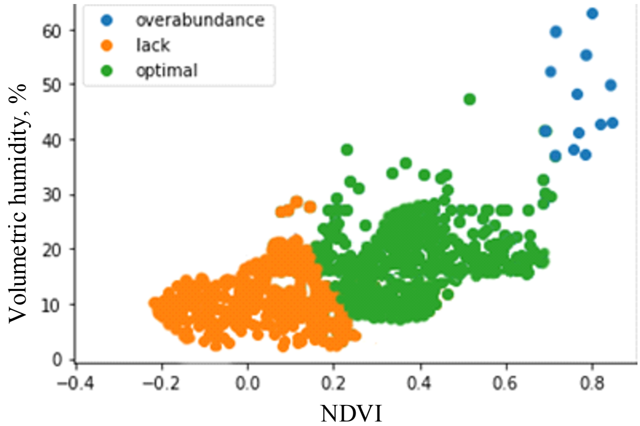


Fig. 3. The result of clustering the values of the test field.

Table 1. Determining whether a field section belongs to the selected classes.

Plot number	Coordinates of the plot	NDVI	Volumetric soil moisture, %	Class
1	42.3128000000 45.0595000000	0.405	27.0517079625	Lk – 0.225 Opt – 0.7 Ovr - 0.075
2	42.3128045193 45.0595265245	0.416	27.0433525472	Lk – 0.22 Opt – 0.705 Ovr - 0.01
3	42.3128049228 45.0595339696	0.425	27.0949690262	Lk – 0.219 Opt – 0.71 Ovr – 0.071
4	42.3127992442 45.0595360275	0.4	27.7985002329	Lk – 0.21 Opt – 0.719 Ovr – 0.071
…	…	…	…	…
49	42.3083011282 45.0513484628	0.05	11.9300848108	Lk – 0.81 Opt – 0.1275 Ovr – 0.0625
50	42.3080981939 45.0509502078	0.0486	8.2161059697	Lk – 0.815 Opt – 0.1275 Ovr – 0.0575
….	…	…	…	…
812	42.3181861801 45.0584515252	0.2	18.8924664361	Lk – 0.493 Opt – 0.5 Ovr – 0.007
813	42.3182545404 45.0584531520	0.197	17.7318322037	Lk – 0.513 Opt – 0.48 Ovr – 0.007

4 Conclusion

The use of the obtained data is possible to interpret the condition of plants. For example, in the case of a high value of soil moisture, but at the same time a low NDVI value in wheat germ, it can be concluded that there is rhizoctonic root rot of wheat. The developed mechanism for assessing the state of plant biomass based on the integration of multispectral optical and radio band sensors can be implemented into an information system, using which an agronomist will receive either a set of data (or a map) indicating the coordinates of abnormal zones, or a set of recommendations on the timing and list of agrotechnical measures to eliminate them. Dividing the field plots into classes allows you to reduce the number of necessary soil analyses and record the variability of various soil properties that can affect crop yields.

The data obtained are used in the operation of the information system to analyze the current state and forecast crop yields.

Acknowledgement

The study was carried out as a part of the implementation of the “Priority 2030” strategic program of academic leadership with the financial support of the Ministry of Education and Science of Russia (Agreement No. 075-15-2021-1319).

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