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Estimation of Soil Moisture from Multispectral Remote Sensing Data

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ABSTRACT

Soil moisture is an important parameter in agricultural and environmental studies and affects the exchange of water and energy at the boundary between the earth's surface and the atmosphere. Accurate estimation of spatial-temporal changes in soil moisture is critical for numerous studies in the agricultural sciences. Vegetation indices, based on combinations of digital data of reflected light in the visible and near-infrared range, are suitable for the detection of water stress in plants. Therefore, they are widely used to monitor and detect drought conditions, but their accuracy is dependent on different vegetation types. The main objective of this research was to develop a novel procedure for the estimation of soil moisture using multispectral remote measurements. This study has been done using a multispectral camera Survey 3W Red+Green+NIR, which records images in three spectral channels: green (550 nm), red (660 nm) and near-infrared (850 nm). Eleven soil samples with different water content were investigated. SNAP (Sentinel Application Platform) software was used to process the captured multispectral images. It allows an easy calculation of various vegetation indices. The suitability of the normalized difference vegetation index (NDVI) for the assessment of soil moisture was evaluated. The average NDVI values did not indicate a well-established trend in relation to the SWC. A new simple vegetation index NIR/Green was successfully used for the assessment of soil moisture. The new NIR/Green index gives consistent results in relation to the real soil water content and could be used for mapping of the soil moisture with multispectral cameras.

Key words: Multispectral remote measurements, NDVI, NIR, Remote sensing, Soil moisture.

The future of agriculture and food security depends to a large extent on overcoming future and current constraints in developing new irrigation systems, which must become more efficient and productive to feed the growing population (Walker, 2011). The use of remote sensing techniques to monitor agricultural variables (water, yield, nutrients, *etc.*) is an existing source of information that can significantly improve agriculture and water management [Anderson *et al.*, 2012; Allen *et al.*, 2011; Kogan, 2001; National Geospatial Advisory Committee (NGAC), 2012].

Soil moisture is an important variable that together with estimates of evapotranspiration can support the assessment of current and future irrigation water needs using water balance techniques (Hassan-Esfahani *et al.*, 2014; Petropoulos, 2013; Hassan-Esfahani *et al.*, 2015).

Satellite sensors can observe large areas of the Earth, but the spatial resolution of the images taken depends on microwave frequency, antenna dimensions and height above the earth's surface. The higher the sensor, the lower the spatial resolution (Lakshmi V, 2013). For that reason, the satellite-based data are used for estimation of the soil moisture and not for direct calculations (Celik, *et al.*, 2022; Efremova, 2021; Liu, *et al.*, 2021; Liang, *et al.*, 2021.

Satellite images had been successfully used for soil moisture estimation using thermal band or optical multispectral bands (Yadav, *et al.*, 2019; Babaeian, *et al.*, 2018; Hassanpour, *et al.*, 2020), but the spatial resolutions of these results are 20, 30 and 100 m (Sentinel-2, or Landsat-5 and Landsat-8/9, respectively). If higher spatial resolution is needed, multispectral cameras, mounted on drones are the better choice (Tmusic *et al.*, 2020).

In recent decades, vegetation indices have gained popularity in remote sensing and management of agricultural fields, based on combinations of digital data of reflected light in the visible and near-infrared range. They give a good idea of the density of the leaf mass but are sensitive to some external factors: the angle of incidence of sunlight and the angle of view of the reflected light, soil background and atmospheric effects. The responses to these factors are complex and complicated and depend on surface characteristics (Qi *et al.*, 1993).

The normalized difference vegetation index (NDVI), the simple ratio (SR) and the enhanced vegetation index (EVI) are the most commonly used. They are also sensitive to water stress and are therefore widely used to monitor and detect drought conditions. However, the accuracy of NDVI-based drought indices is often subject to changes in different vegetation types and ecosystem differences.

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Several classic drought indices based on vegetation indicators have been proposed and are widely used in drought monitoring (Kogan, 1990; Kogan, 1995; Rouse *et al.*, 1973).

The main objective of this study was to develop a novel procedure for the assessment of soil moisture using multispectral imaging techniques. The suitability of the normalized difference vegetation index (NDVI) for the assessment of soil moisture is also evaluated.

The reported research was carried out at the Agricultural University of Plovdiv during the period May 2020-January 2021.

This study has been done using a multispectral camera Survey 3W Red+Green+NIR, which records images in three spectral channels: green (550 nm), red (660 nm) and near-infrared (850 nm). Eleven soil samples with different water content were investigated. Initially, all samples were filled with dry peat spilled with a mass of 100 grams. Ten minutes before the images were taken, water is added to the samples as shown in Table 1.

The results obtained with the multispectral camera Survey 3W Red+Green+NIR were used to calculate the Normalized Difference Vegetation Index, or NDVI, introduced in the early seventies (Rouse *et al*., 1973), expressed as:

$$NDVI = \frac{NIR-R}{NIR+R} \quad \text{....(1)}$$

Where

NIR = Digital value of the reflected light in the near-infrared channel.

R = Value for the red channel.

NDVI results are shown in Fig 1b. The figure shows that there's not a good enough contrast between different soil moisture. The obtained NDVI values for the different soil samples vary between -0.34 and 0.14 (Fig 1b). The results of the NDVI values and the soil water content (SWC) showed that there is an inverse relationship between these two quantities: when the SWC is increasing, the NDVI values are decreasing. The average NDVI values did not indicate a well-established trend in relation to the SWC. For that reason, numerous simple ratios between different channels were investigated. Some of the new vegetation indices give better resolution and sensitivity to soil moisture.

It was found that the ratio NIR/Green gives the best information and sensitivity to soil moisture, working with the data from the investigation spectral channels. The results for this ratio are presented in Fig 1c. NIR/Green values vary in the range from 0 to 3.6. The average NIR/Green values for different soil samples are shown in Table 2.

The results show that the NIR/Green index increases with increasing of the water content in the samples. This is because the water absorption is strong in the NIR wavelength area.

The new NIR/Green index gives consistent results in relation to the real soil water content and could be used for mapping of the soil moisture with multispectral cameras, mounted on drones. The results show a great potential for receiving real reliable remote sensing data for the soil water content of the land using the simple NIR/Green.

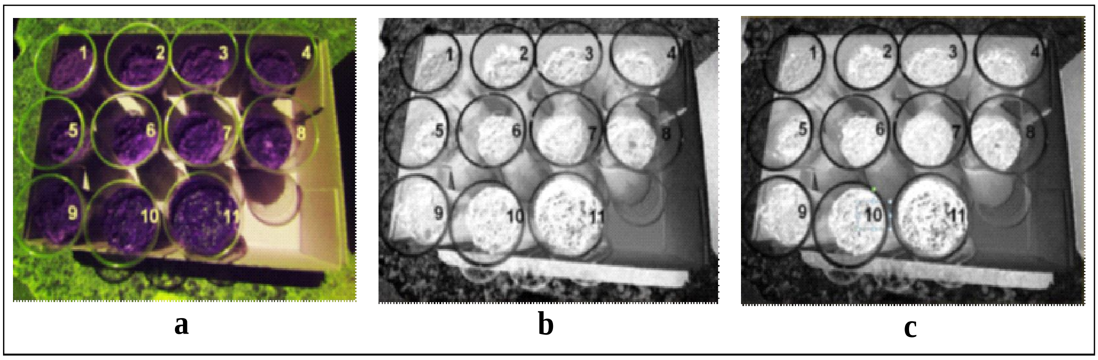

Fig 1: Images of soil samples with different moisture: Surwey 3W Camera image (a), NDVI image (b), NIR/Green image (c).

Table 1: Soil samples with different water content.

Sample	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
Number on Fig 1	1	2	3	4	5	6	7	8	9	10	11
Water, ml	0	10	20	30	40	50	60	70	80	90	100

Table 2: NIR/Green index for soil samples with different moisture.

Sample	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
Number on Fig 1	1	2	3	4	5	6	7	8	9	10	11
NIR/Green	1.60	2.04	2.06	2.11	2.23	2.59	2.30	2.36	2.37	2.42	2.57

CONCLUSION

The measurements made and the analysis performed allow us to formulate the following main conclusions:

1. Multispectral remote sensing was applied for the estimation of soil moisture.
2. It was shown that the normalized difference vegetation index (NDVI) can be utilized for the assessment of soil moisture.
3. It was shown that a new simple vegetation index (NIR/Green) can be used successfully for the assessment of soil moisture.
4. Further studies have to be done to evaluate the suitability of the NIR/Green index for different types of soil because different soils have different reflectance spectra.

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Conflict of interest

All author declare that they have no conflict of interest.

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