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DROUGHT VEGETATION MONITORING USING *IN SITU* AND SATELLITE DATA, IN THE CARACAL PLAIN OF ROMANIA

LAURA MIHAI[1], A. STANCALIE[1], ADELINA SPOREA[1], D. SPOREA[1], ARGENTINA NERTAN[2], D. MIHAILESCU[2]

[1] National Institute for Laser, Plasma and Radiation Physics, Atomistilor 409, Magurele, Ilfov, Romania, Email: laura.mihai@inflpr.ro
[2] National Meteorological Administration 97, Soseaua Bucuresti-Ploiesti, sector 1, Bucharest, Romania

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Abstract. Drought monitoring and plant productivity can be qualitatively evaluated using vegetation indices. In this paper, we combined *in-situ* reflectance, satellite and agro-meteorological data, in order to obtain and analyze high precision indices corresponding to germination period of some agricultural crops from the Caracal plain, Romania. Sensitivity tests regarding the effect of detection angle and atmospheric conditions on reflectance were estimated. Differences that can be related to the phenological stages of studied crops were noticed in near infrared spectral range. The *in-situ* and satellite–based results, correlated with main agro-meteorological parameters proved to be good indicators of the drought vegetation condition.

Key words: agriculture crops, in-situ spectral reflectance, vegetation indices, LAI, fAPAR

1. INTRODUCTION

Solar radiation impact on vegetation is very important in studying the phenological stages and the crops yield, since the exposure of the canopy solar radiation directly affect the photosynthesis process. The measured reflectance for a surface covered with vegetation is dependent on many factors like the canopy geometry, the plant morphology and psychology, its bio-chemistry, the soil type, the solar angle and climate conditions [1]. Vegetation reflectance is being influenced mostly by optical properties of plants components – that contain mostly carbon, oxygen and nitrogen. Typically, the measured spectra can be divided in some specific spectral ranges, in relation to the reflectance controlling factors. For example, in the visible range VIS (divided in BLUE: 400–500 nm and RED: 500–700 nm) the main contributions appear from the leaf pigments (green, carotene, xanthophyll) which strongly absorb in BLUE. The chlorophyll is the main absorber in RED, and the internal structure of the plant (such as spongy mesophyll cells) is responsible for the strong reflectance in near infrared range NIR (700–1300 nm). The water and moisture stress can be analyzed from reflectance in the shortwave infrared range – SWIR (1300–1800 nm) (Fig. 1). Also, an important area in the spectrum is the "Red Edge" that marks the boundary between chlorophyll absorption and plant internal structure reflectance [2, 3].

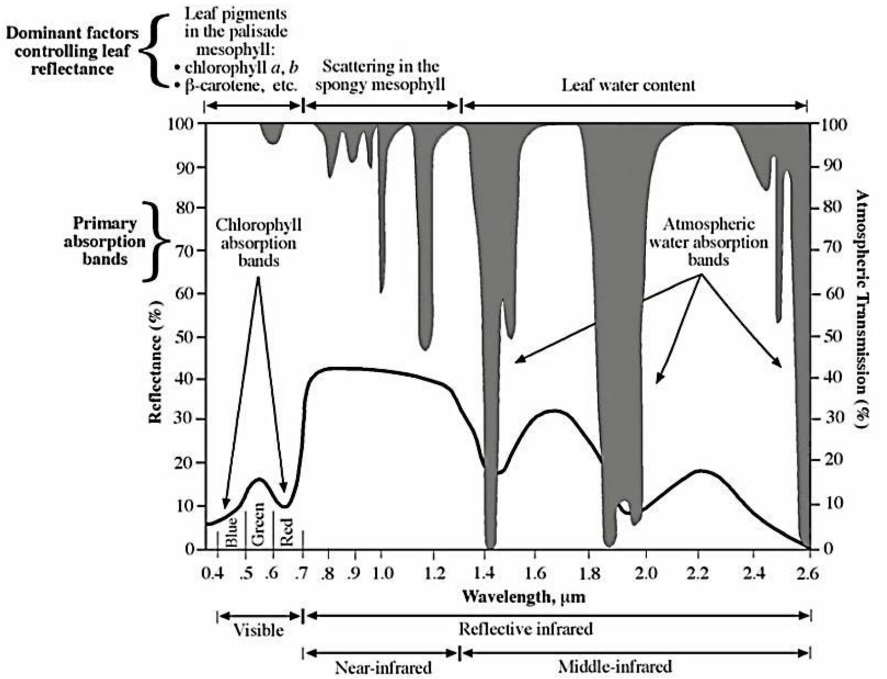


Fig. 1 – Primary absorption bands and factors responsible for changes in the spectral reflectance curve [4].

Measurements must be carried out with great accuracy and precision, since there are many factors that can determine the spectral response. These factors can be influenced by the experimental setup, the environment conditions or can be related to the response of the spectrometers used. Moreover, there are no national or international standards for *in-situ* data collection and the methods used do not allow ground data recording so that a good traceability is required. Tests cannot be carried in same conditions for a large number of points to have a higher spatial resolution, and many times measurements are done in only one site [5]. Methods are not described with accuracy and the results vary in space and time. For this reasons, in order to be able to improve the quality of the spectral data acquired, it is necessary to pay special attention to the means used for spectral data acquisition.

In this study, the evaluation of the *in situ* and satellite spectral reflectance data was done, corresponding to three different agricultural crops (wheat, corn and sunflower) in the range of VIS – NIR. Results were obtained in the frame of the STAR 2012 Program – DROMOSIS project (Drought monitoring based on space and in-situ data) (http://dromosis.asrc.ro). This project exploits the main advantage of remote sensing techniques – in synergy with the classic in-situ data collection techniques regarding reflectance measurements, providing continuous coverage at high spatial and temporal resolution of large geographic areas.

The relation between crop spectral absorption/reflectance and the water and nitrogen content in plants is specified by vegetation indices (VIs), determined from reflectance measurements at some specific wavelengths, or by the biophysical variables that are related to photosynthesis, evapotranspiration, and productivity of agro-ecosystems (*e.g.* Leaf Area Index – LAI and Fraction of Absorbed Photosynthetically Active Radiation – fAPAR). For higher precision of reflectance measurements, a special attention was paid to some sensitivity tests such as changes of the detection angle, number of measurements sites and the tests reproducibility. Remote sensing and ground based measurements results were quite similar, highlighting the effect of reduced precipitation and soil moisture on the studied crops.

2. DATA COLLECTION AND ANALYSIS

Three different crops with different leaf characteristics (sunflower, corn and wheat) were selected for sampling in three consecutive campaigns from May to August 2013. The sampling periods were chosen to correspond with the phenological stages of the crops. The study area selected for *in-situ* measurements is located in the Caracal Plain in the Southern part of Romania, at the Agricultural Research and Development Unit of Caracal (N44°06', E24°21', altitude 98 m, Fig. 2). The Caracal Plain has a temperate climate with Mediterranean influences, characterized by winters which alternate in frost and defrost phenomenon, with 2–3 dry months per year and the maximum amount of precipitations in June.

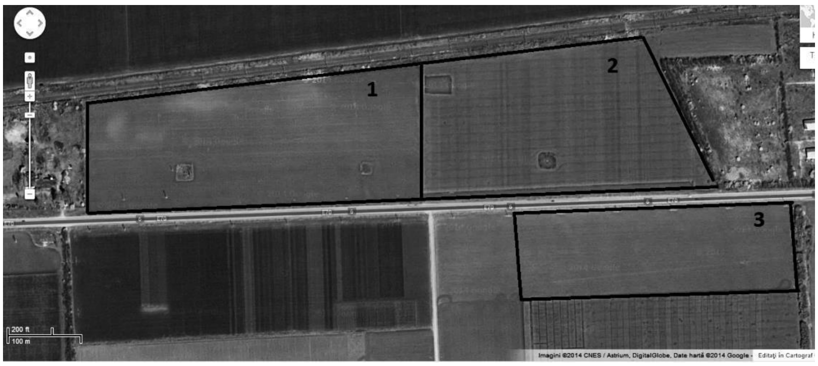


Fig. 2 – The studied area of 1 – corn, 2 – wheat, 3 – sunflower crops parcels selected for *in-situ* reflectance and LAI/fAPAR biophysical variables measurements.

Spectral reflectance was measured by placing an optical fiber spectrometer system (Fig. 3) equipped with the cosine corrector CC-3-UV/-S (angle of view of 180 ^{o}) at approximately 1.5 meter above sunflower crop and 1 meter above the corn crop. As a reflectance reference the WS-1-SL standard was used. Samplings were achieved in five (for sunflower) and three (for corn) different sites along the canopy, located at 10 meters apart one to the other, in clear sky atmospheric conditions. The reflectance dependence on the leaves shape, size and position was evaluated by rotating the spectrometer detecting head to the four cardinal directions (at 90 ^{o}), for each sampling point. Based on the spectral reflectance results the vegetation indices presented in Table 1, were computed to estimate the solar radiation effect on plant constituents, at specific wavelengths.

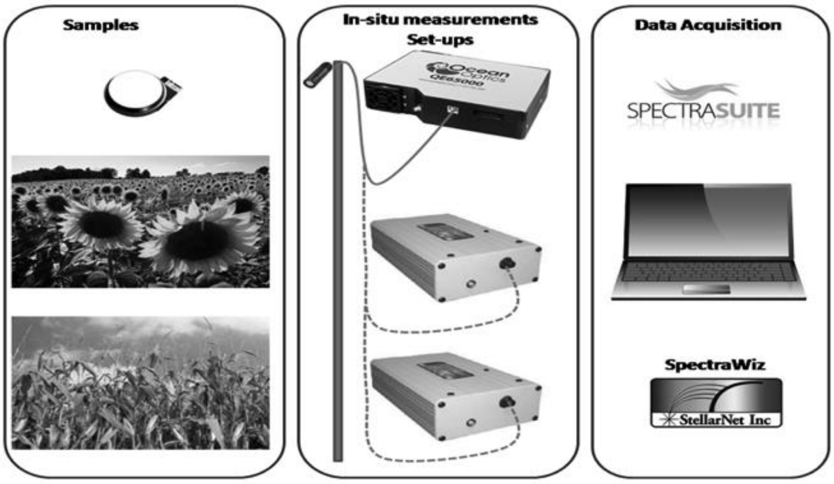


Fig. 3 – The spectral reflectance measurement setup.

The space-borne sensors provide physically based and consistent spatial information over space and time, useful for crops vegetation state monitoring and assessment. From the satellite data can be computed different vegetation indices, designed to accentuate a particular vegetation property and some biophysical, biological or structural vegetation parameters.

For this study the satellite data used were provided by the TERRA-Modis, SPOT-Vegetation and the PLÉIADES constellation. The MODIS instrument is one a key instruments onboard the USA Aqua satellites. The spectral bands most applicable for vegetation studies are in the VIS, NIR and SWIR range at a 250 m and 500 m spatial resolution. The SPOT VEGETATION S10 product with 1 km resolution is composed by merging atmospherically corrected segments acquired over a ten days interval. All the segments of a decade are compared again pixel by pixel to pick out the ‘best’ ground reflectance values. The SPOT VEGETATION is successfully continued by the new PROBA-V ESA satellite mission, launched in May 2013, with the main task of mapping land cover and vegetation growth across the Earth every two days. This mission is extending the data set of the long-established SPOT Vegetation, but with an improved 350 m spatial resolution. The PLÉIADES consists of four new satellites: PLÉIADES 1A & 1B and SPOT 6 & 7, being able to ensure the continuity of Earth optical imaging service up to 2023. These satellites combine a twice-daily revisit capability with an ingenious range of resolutions. For this study three Pleiades satellite images were acquired in May, July and August 2013, covering the test area of Caracal in the South of Romania.

Leaf Area Index (LAI) variable defines the number of equivalent layers of leaves relative to a unit of ground area. The LAI variable is used as satellite-derived parameter for calculating surface photosynthesis, evapotranspiration, and net primary production, which in turn are used to calculate terrestrial energy, carbon, water cycle processes, and biogeochemistry of vegetation.

Fraction of Absorbed Photosynthetically Active Radiation Index (fAPAR) is a non-dimensional parameter that measures the fraction of the incoming solar radiation at the top of the vegetation canopy that contributes to the photosynthetic activity of plants. fAPAR is a biophysical variable directly correlated with the primary productivity of the vegetation being a good indicator to detect and assess the impact of drought on vegetation cover (crops, natural vegetation).

For this study were made indirect measurements (optical measurements) of LAI / fAPAR using the ceptometer AccuPAR LP-80. AccuPAR LP-80 (Fig. 4) is an optical instrument for measuring LAI and fAPAR.

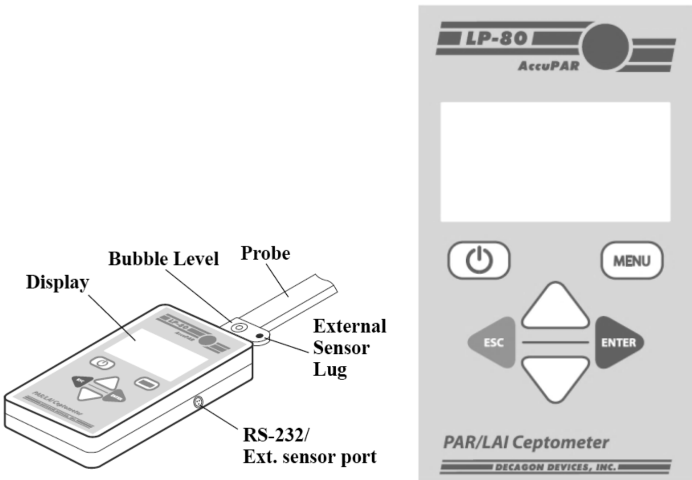


Fig. 4 – AccuPar LP-80 instrument.

The device measures canopy PAR interception and calculate LAI at any location within a plant or forest canopy. fAPAR data can be used with other climate data to estimate biomass production without destroying the crop. fAPAR is also important in determining other canopy processes; such as radiation interception, energy conversion, momentum, gas exchange, precipitation interception, and evapotranspiration (http:// http:// www.decagon.com). The AccuPAR also uses radiation measurements and other parameters to accurately calculate LAI non-destructively in real time, in the field.

During the three field campaigns were performed LAI and fAPAR measurements in 26 points for sunflower (Fig. 5), 32 points for corn and 7 points for the wheat crop.

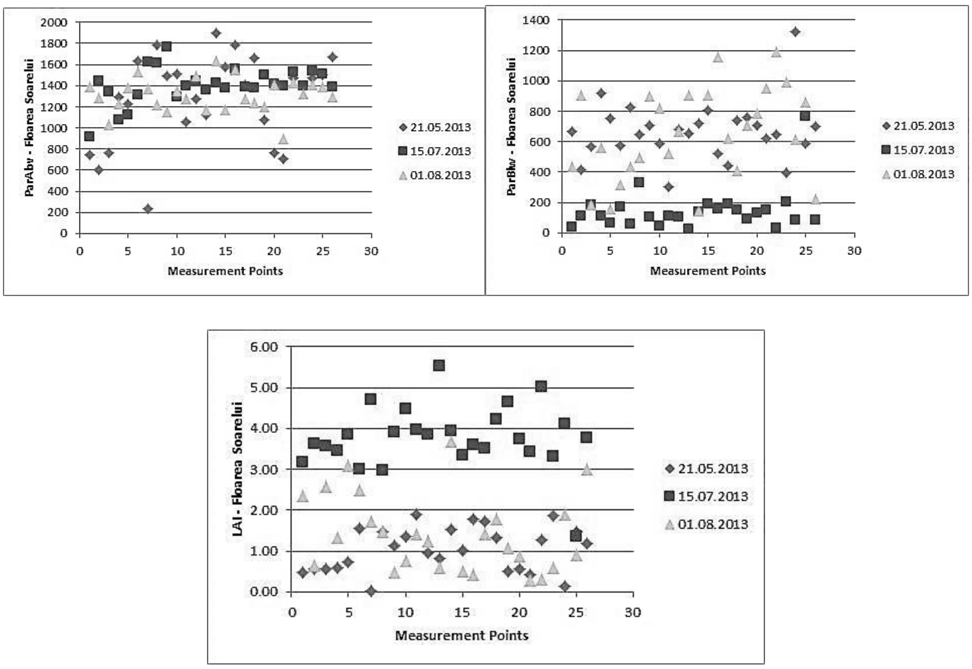


Fig. 5 – fAPAR and LAI measurements for sun flower crop.

Agro-meteorological data were provided by the weather station in Caracal and from *in situ* soil moisture measurements, performed using Delta-T Device system HH2, that includes: the profile probes (soil moisture measurement probe), the theta probes (soil moisture sensor that measures only), the SM300 sensor (that measures both soil moisture and temperature) the echitensiometer and the tri-WET sensor (sensor measuring soil water content and soil conductivity) (Fig. 6).

For each type of crop were performed several measurements of volumetric water content of the soil (%) at various depths in the range of 0–100 cm. Figure 7 presents the obtained volumetric water content for the sunflower in different parcels.

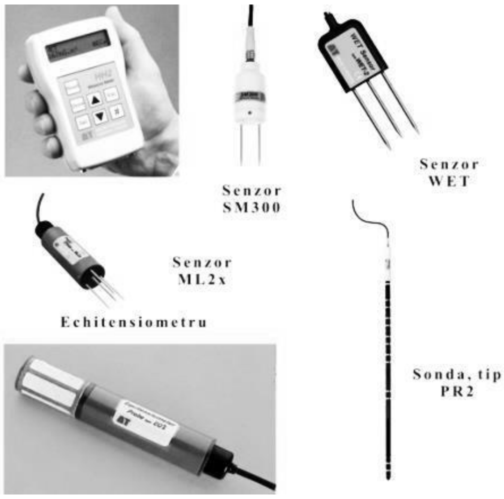


Fig. 6 – Soil moisture meter HH2 (Delta-T Device System).

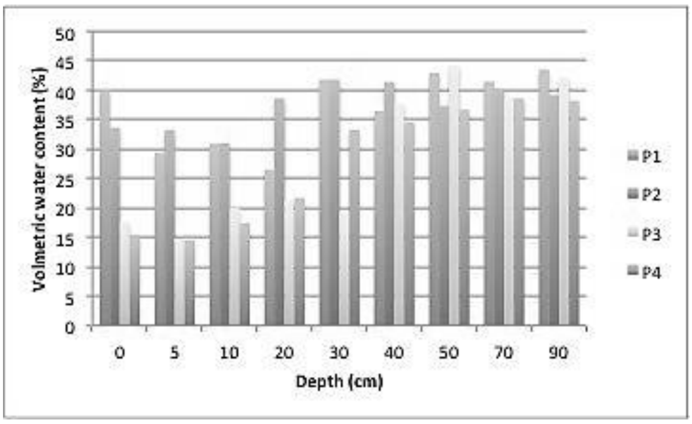


Fig. 7 – Volumetric water content for sun flower.

3. RESULTS AND DISCUSSION

The results of *in-situ* spectral reflectance measurements corresponding to the growing stages of sunflower and corn from the study area Caracal Plain are represented in Fig. 8a and 8b. For sunflower crop, the minimum values can be observed around 500 nm and 680 nm (related to the absorbed solar radiation by plant pigments and chlorophyll), with a maximum value between them (around 550 nm) for the flowering stage (15^{th} July). Besides, an abrupt increase around 700 nm (red edge) appears due to the strong radiation scattering by leaf cells. All these characteristics (that correspond to a healthy plant) are not so visible for the following recorded phenological stage (1st August), because, even if the new tissue cells of plants are present, the old ones with a lower chlorophyll concentration contribute to the reflectance decrease in NIR. The plant aging and the cells necrosis was also noticed in the case of corn reflectance spectrum (Fig. 8a and 8b), as data were collected in the reproductive stage of corn (July-August). On the other hand, the noise present in reflectance data recorded in August can be related to the atmospheric conditions (partially clouded sky).

Sensitivity studies were conducted for the reflectance measurements and the results are presented in Fig. 9, where some discrepancies are noticeable. In the first graph (Fig. 9a), when the sampling location was changed, the differences in reflectance values can be explained by the canopy geometry (its non-uniformity) and by alteration of the atmospheric conditions (low and transparent clouds covering). In the second graph (Fig. 9b), when the sensitivity to illumination and to the detecting geometry was evaluated, the variations in reflectance can be related to leaves geometry (size, shape) and orientation. Also, the differences can be justified by the backward scattering sampling originating from sunlit leaves, the reflectance in this case being higher, while in the case of forward scattering sampling the signal originates mostly from shaded leaves, and the reflectance is reduced [6, 19, 20]. The measurement reproducibility was very good as can be observed from Fig. 9c.

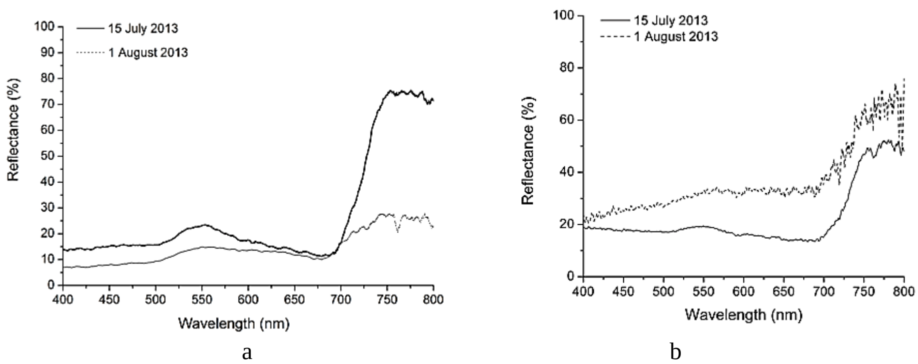
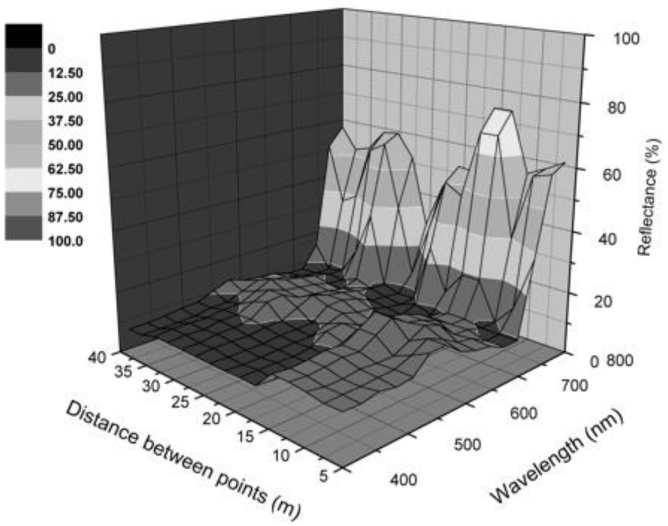
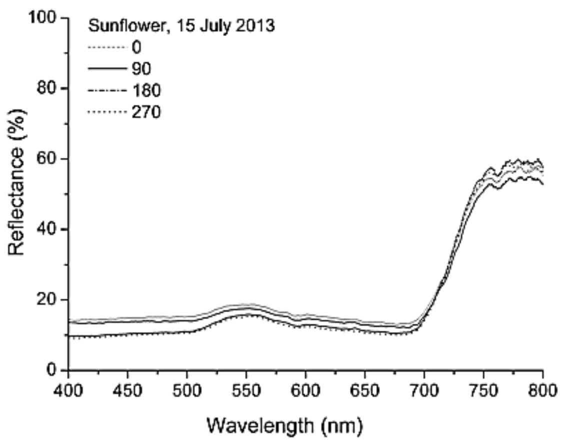


Fig. 8 – Canopy spectral reflectance characteristics of sunflower (a) and corn (b) related to their growing stages: 15 July and 1 August 2013.

The behavior of the studied crops at different wavelengths and over specific spectral ranges was studied by computing the vegetation indices (VIs). Their values are presented in Table 1. Generally, the decrease of the spectral reflectance in NIR induces a decrease of the vegetation indices, and is illustrated by the reported results. The decreased values of Red Edge Normalized Differences Vegetation Index 705, the normal values of Plant Senescence Reflectance Index and Photochemical Reflectance Index emphasize the foliage content changes of the studied crops in August. In the same period, the Structure Independent Vegetation Index values below the normal values of a healthy plant (0.8–1.8) can be attributed to a lower ratio of bulk carotenoids/chlorophyll. The values around 1 obtained for Signal noise index indicate that in August the quantity of light scattered by plant structure was almost equal to that absorbed by the leaf pigments. The other VIs presented in Tabel 1, have normal values.

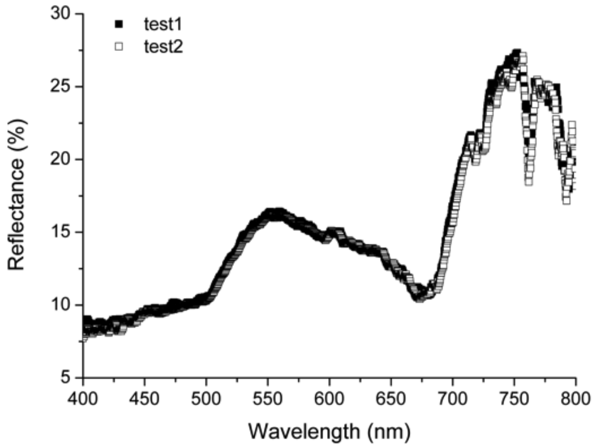


a.



b.

Fig. 9



c.

Fig. 9 (continued) – Reflectance data sensitivity to the change of sampling point along the canopy (a), of viewing direction (b) and the reproducibility for the studied crops (c).

Table 1

Vegetation indices corresponding to sunflower and corn crops for 2 growing stages

Vegetation indices	**Formula**	**Sunflower**		**Corn**	
		15th July 2013	*1st August 2013*	*15th July 2013*	*1st August 2013*
REIP Red Index Inflection Point	$700+40[(R_{667}+R_{782})/2 - R_{702}]/(R_{738}-R_{702})$ [7]	722.297	727.995	702.161	723.307
NDVI Normalized Differences Vegetation Index	$(R_{782}-R_{667})/(R_{782}+R_{667})$ [7]	0.669	0.602	0.271	0.223
NDVI705 Red Edge 705	$(R_{750}-R_{705})/(R_{750}+R_{705})$	0.484	0.464	**0.184**	**0.174**
SIPI Structure Independent Vegetation Index	$(R_{800}-R_{445})/(R_{800}+R_{445})$ [8]	**0.682**	**0.546**	**0.275**	**0.241**
PSRI Plant Senescence Reflectance Index	(R680 - R500)/(R750)	-0.009	-0.036	-0.043	0.086
PRI Photochemical Reflectance Index	$(R_{531}-R_{570})/(R_{531}+R_{570})$ [9]	-0.001	0.018	-0.007	-0.021
GI Greenness Index	R_{554}/R_{677} [10]	1.480	1.327	1.365	0.914
CIG Green Chlorophyll Index	$(R_{800}/R_{550})-1$ [11]	2.527	2.005	0.409	0.390
SRPI Simple ratio pigment index	R430/R680 [12]	0.944	1.245	1.079	0.799

The satellite based VIs are important tool for vegetation condition monitoring and evaluation because of the accurate discrimination and correlations with biophysical parameters which determine the vegetation state. The most important VIs for vegetation monitoring include the "broadband greenness" category (*e.g*. Normalized Difference Vegetation Index - NDVI, Soil Adjusted Vegetative Index - SAVI, Enhanced Vegetation Index-EVI, etc) and the "canopy water content" category (*e.g*. Normalized Difference Water Index-NDWI, Normalized Difference Drought Index – NDDI, etc.) [13, 14, 15].

The Normalized Difference Vegetation Index (NDVI) is considered as a reliable measure of the amount and vigor of vegetation [13, 16]. The value of NDVI ranges from –1 to 1. The common range for green vegetation is 0.2 to 0.8. NDVI was calculated from MODIS Surface Reflectance product (MOD09A1) using NIR and RED spectral channels. To highlight the importance of VIs in vegetation state monitoring the NDVI SPOT Vegetation product was also used.

Figure 10 presents the Spot-Vegetation-derived NDVI evolution *versus* precipitation (recorded at Caracal weather station) for March–September 2013. It can be noticed that, although in the April-May period the precipitation amounts were small, the NDVI values increased, due to the existed in-soil water reserve, accumulated from the precipitation fallen in March to 10 April, 2013. However, due to the scarce amount of precipitation (in the periods 11 April–10 June 2013 and 11.07–20 August 2013) the vegetation state of the crops was affected by drought, situation highlighted by the NDVI decrease trend. Owed to the spatial resolution of the SPOT Vegetation image products (1 km) and to the small size of the parcels, no clear delimitation can be made between the various crop types.

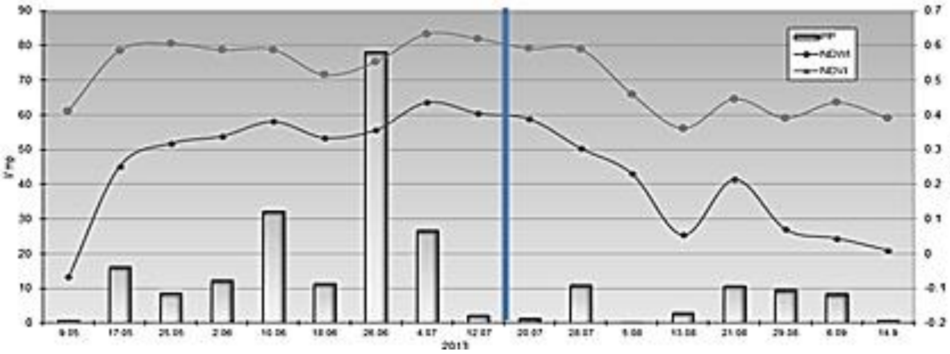


Fig. 10 – Spot-Vegetation derived NDVI evolution *versus* precipitation (recorded at Caracal weather station) for March–September 2013.

The Normalized Difference Water Index (NDWI) is a satellite-derived index from the NIR and the short wave infrared (SWIR) reflectance channels [17]. The SWIR reflectance reflects changes in both the vegetation water content and the spongy mesophyll structure in vegetation canopies, while the NIR reflectance is affected by leaf internal structure and leaf dry matter content but not by water content. NDWI holds considerable potential for drought monitoring because the two spectral bands used for its calculation are responsive to changes in the water content (SWIR band). This index increases with vegetation water content or from dry soil to free water [13, 18]. The NDWI value ranges from –1 to 1. The common range for green vegetation is –0.1 to 0.4.

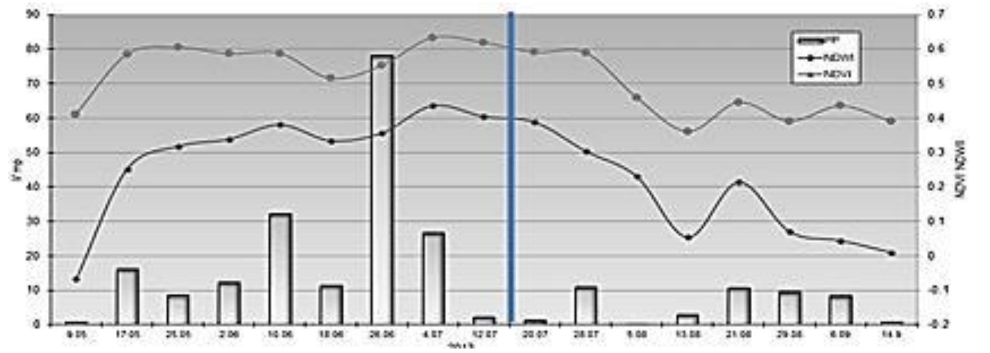


Fig. 11 – MODIS-NDVI and NDWI (250 m resolution) evolution *versus* precipitation (recorded at Caracal weather station) for May – September 2013 (for the wheat crop).

Figure 11 highlights the MODIS derived NDVI and NDWI (250 m resolution) evolution *versus* precipitation for May – September 2013 period, for the wheat crop. A minimum NDVI value was noticed at the beginning of May, due to the lack of precipitation. Further, due to the precipitation recorded in May and June, the NDVI values returned to normal (> 0.6). A NDVI decrease trend can be noticed over the interval when wheat was harvested (July). The same trend can be seen in the course of NDWI. The higher values of NDWI (~0.4) correspond to medium vegetation water content and to medium vegetation fraction cover.

Table 2 presents the NDVI values computed from the Pleiades satellite data, for wheat, corn and sun flower crops in the study area, for three dates associated with the satellite images acquisition.

As it can be observed the NDVI values for wheat correspond to the starting process of maturity and for corn and sunflower the NDVI values to the first stage of leaf development (10 May 2013). At the beginning of July wheat was on harvesting phase and the NDVI reached the minimum level. Corn and sunflower were in the flowering and fertilization phases (NDVI~0.7). In August, corn and sunflower were in the grain filling and maturity stages, but the NDVI values are lower due to lack of precipitation from middle of July.

Table 2

Vegetation indices derived from Pleiades satellite data

	Wheat			Corn			Sunflower		
Satellite data acquisition	10-May-2013	3-Jul-2013	26-Aug-2013	10-May-2013	3-Jul-2013	26-Aug-2013	10-May-2013	3-Jul-2013	26-Aug-2013
NDVI	0.824	0.235	0.246	0.166	0.687	0.704	0.124	0.23	0.156

4. CONCLUSIONS

In-situ spectral reflectance data were used to characterize three types of crops from Caracal Plain. The reflectance and vegetation indices values emphasized the plants stress along its phenological stages. Data were compared to the agro-meteorological data, and the relation between the plant stress and the reduced precipitation level and soil moisture was observed. A good correlation was obtained also from NDWI (determined from satellite data) and the measured humidity in soil.

Ground-based data on the investigated crops were used to complement satellite data, the results being used to introduce atmosphere related corrections to satellite observations. The integrative approach based on *in-situ* spectral measurements together with agro-meteorological ones and with satellite data/products enhances and improves the crop vegetation state monitoring and the drought analysis.

Different satellite-derived vegetation indices (*e.g.* NDVI, EVI, NDWI and NDDI) and biophysical variables (LAI, fAPAR) proved to be good indicators of the vegetation condition and relevant for the settlement, duration and intensity of the agricultural drought.

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