Bulgarian Academy of Sciences. Space Research and Technology Institute.
Aerospace Research in Bulgaria. 37, 2025, Sofia

STUDY THE APPLICABILITY OF SENTINEL-2 OPTICAL DATA, AS WELL AS BENEFITS FROM THE SENTINEL-1 SAR DATA, FOR PREDICTING THE YIELD OF ORGANIC BARLEY

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Keywords: *Remote sensing, Sentinel-2, Sentinel-1, Organic farming, Barley, Yield*

Abstract

The barley crop is widely used in the economic life of humanity and is characterized by great ecological plasticity. It is a good competitor to other cereals, which is why it is extremely suitable for growing in organic farming. The multispectral data obtained from the COPERNICUS Sentinel-2 satellites has proven in numerous scientific works its applicability to support crop monitoring. In that way, that data is invaluable in optimizing the production processes. In this study, a comparison was made between satellite data products derived from the COPERNICUS Sentinel-2 optical and Sentinel-1 SAR data, as well as studying their statistical relationship with the yield of the organically grown barley. The spatial resolution of all products is 10 m. The utilization of both satellite data types for monitoring and forecasting the yield of organically grown barley has been verified. The BBCH-41 phase was found to be the most suitable for the utilization of Sentinel-2 optical data to generate a different set of vegetation indices for yield prediction. In that phase, most of the tested vegetation indices showed successful yield prediction. The most relevant is the Green Chlorophyll Vegetation Index (GCVI; r = 0.80), which has the highest correlation with the yield. Considering SAR data, the backscatter in co- and cross-pol were derived in terms of Sigma-Nought. The Radar Vegetation Index in dual-pol (dRVI) was also calculated. As reported in other studies, a correlation is observed between dRVI and vegetation indices (e.g., NDVI). Whole output SAR products are sensitive to the geometrical properties of the crop and represent in various extent the phenological development of the organic barley. In this regard, SAR data complements optical data and provides reliable information on crop conditions during periods of high cloud cover. Bearing in mind that very often these periods coincide with phenological phases that are critical in crop development.

Introduction

Barley remains an important crop for feeding the population, especially in dense and poor population areas such as Asia and North Africa, with an increased interest in it worldwide due to its good nutritional qualities [1]. Besides nowadays satellite data find various applications for monitoring objects in outer space such as the moon [2], but also a great application for observations of the earth, such as atmospheric pollution [3], management and monitoring of landfills [4], glaciers and permafrost [5], monitoring of fires and the processes of restoration of territories after fires [6], one of the main applications is for crop monitoring [7]. The application of such data in agricultural management could foster decision-making, mostly in organic agriculture [8]. The combined use of Sentinel-1 and Sentinel-2 data allows monitoring of plant growth conditions with high spatial resolution [9]. In scientific literature, active microwave systems, such as Synthetic Aperture Radar (SAR) [10], are also well utilized in agricultural studies. The high utilization value of the C-band COPERNICUS ESA's Sentinel-1 SAR (S1) satellite system with its dual-polarization capabilities has proven its sensitivity to the geometrical structure of crops by means of the dual-pol Radar Vegetation Index [11]. Also, S1 dual-polarization SAR has been successfully utilized in land cover mapping of the natural scatterers, especially crops [12]. By understanding the temporal behavior of the SAR backscatter from S1 of the cross-pol (VH) with respect to the co-pol (VV), a conclusion may be drawn about the crop development during the growing season [13]. Because of that sensitivity, SAR data also find high feasibility in classifications and phenology phases determination of different types of crops [14]. Furthermore, the combination of optical and radar data shows susceptibility of distinguishing different types of cereal crops [15]. This type of data is used in predicting wheat yields grown under conventional farming conditions [16]. The SAR systems are valuable in the monitoring of agricultural crops, since unlike the optical ones, measurements are not affected by meteorological conditions, nor depend on a celestial body for illumination, for the sake of active microwave systems [17].

The general objective of the study is to test which satellite data type, provided by S1 or S2, is more suitable to be used in monitoring organic barley yield, and how much the calculated indices correlate with the biophysical parameters.

Materials and Methods

Study area

This study was conducted in the agricultural year 2022-2023, with the study area located in the land of the village of Byala Reka, Parvomay municipality region, Plovdiv in South-Central Bulgaria. The ground yield data are collected from an organically certified field planted with barley, which is part of the farm of ET "Borislav Slavchev", Fig. 1.

Fig. 1. Map of the location of the study field

Methodology

The general aim of the methodology is to test statistical correlation between satellite observables from optical and SAR data, and in-situ measurements of biological and physical parameters of organic barley, during its phenological phases. The common methodology is presented in Fig. 2.

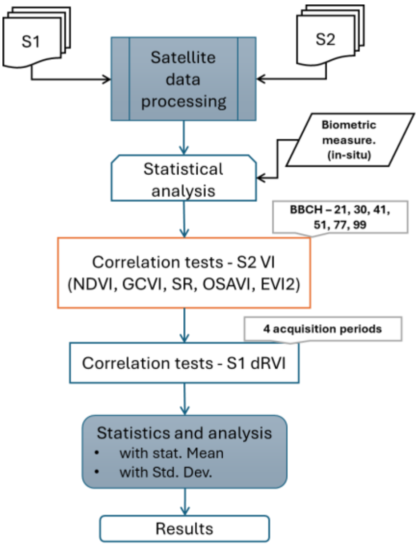

Fig. 2. Methodology that aims to derive correlation results from satellite data with the in-situ measurements

Phenological observations

Registration of the main phenological phases was made using the BBCH scale–BBCH-41 early boot stage and BBCH-51 beginning of panicle emergence [18]. The onset of each phase is when 25% of the plants have entered it. Reporting takes place when 75% of plants are covered in the relevant phase. In the EOS Crop-monitoring platform in phenological phase tillering BBCH-21, three pixels were selected in the field with vegetation index NDVI values of 0.8, 0.7, and 0.6, respectively. The pixels have a size of 20 m × 20 m, and in each of them, a sample site with dimensions of 10 m × 10 m is organized. Upon reaching the technological maturity phase, BBCH-99, GPS coordinates were taken at the four ends of the trial site, and all plants of 4 plots, each sized 0.25 m × 0.25 m.

Biometric measurements

Biometric studies were made using the methodology of Shanin (1977) [19]. Before harvesting, all plants of 0.25 m × 0.25 m in 4 replicates are taken in the three different levels of the NDVI vegetation index. In each plot all plants were counted, and on 25 plants the following indicators were tracked: Plant height (cm); Class length (cm); Grains in the class (number); Grain mass in the class (g); Biological yield (kg/da); Physical qualities of the grain; Mass per 1000 grains (g) for four replicates.

Optical data

In the GIS environment, the pixel values for each of the sample sites in the field were extracted from the generated vegetation indices (VI) for all of the studied fields by means of the optical data from S2 and SAR from S1. Hence, the following vegetation indices were utilized in the study: GCVI, SR, OSAVI, and EVI2. Furthermore, thematic maps were elaborated for the field studied, together with the corresponding VI (Fig. 3). In the next step, yield maps for the field under investigation were elaborated using VI and yield data.

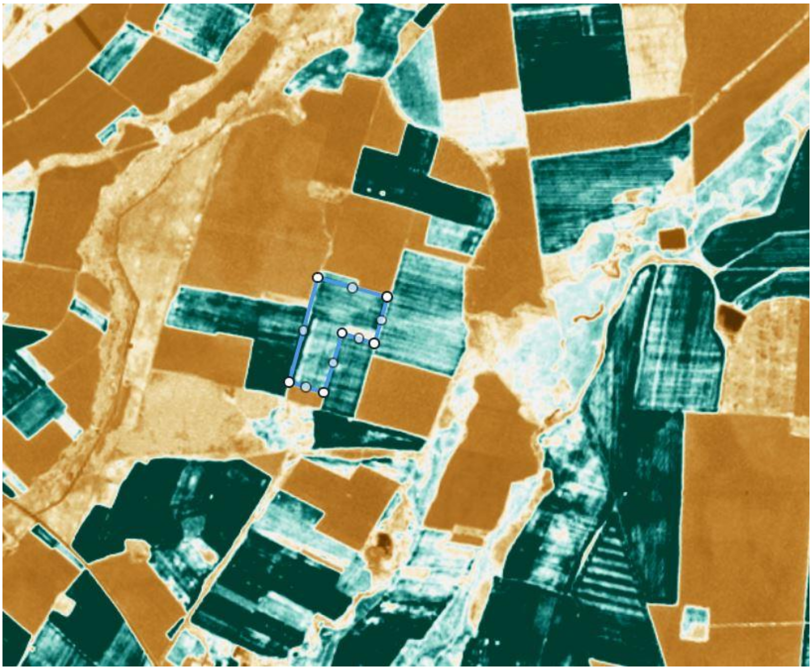

Fig. 3 GCVI index calculated from S2 data, with test area boundary overlaid

SAR data

Radar measurements from the Copernicus mission Sentinel-1 C-band dual polarization SAR instrument were used to complement the study. Ground Range Detected (GRD) products are utilized in ascending (ASC) and descending (DESC) orbits, which refers to an early morning acquisition at about 4 h local time, and afternoon acquisition at about 16 h local time. The approach considers orbit averaging of two adjacent acquisitions in the span of four months during crop development, having the following dates corresponding to the in-situ measurements:

- 5.3.2023 (ASC), 6.3.2023 (DESC)
- 17.4.2023 (ASC), 18.4.2023 (DESC)
- 29.4.2023 (ASC), 30.4.2023 (DESC)
- 23.5.2023 (ASC), 24.5.2023 (DESC)

Radar processing comprises Sigma-Nought calculation for both polarizations, Lee-speckle filter with a window size of 3x3, conversion of linear values to decibels (dB), and terrain correction. The dual-pol Radar Vegetation Index (dRVI) is then calculated from both polarizations [11]. SAR processing is held in ESA SNAP software, represented in Fig. 4.

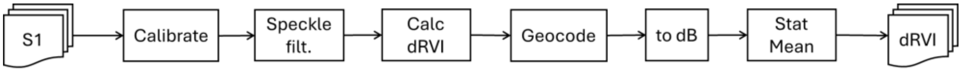

Fig. 4. Processing steps of SAR dual-poi data from S1, in SNAP

An orbit averaging is performed from ASC and DESC orbits, representing the final SAR estimation of the organic barley during terrain campaigns (Fig. 5).

Fig. 5. The orbit-averaged dRVI index, calculated from S1 SAR GRD products at the test area with organic barley, covering four time periods from March to May 2023

Statistical analyses

In the proposed methodology, statistical relationships are studied with optical but also with SAR observables. Spatial statistical analysis is held in QGIS and ArcGisPro©, where buffers with a radius of 10 m around the in-situ points are created to be used as “zones” in the concurrent zonal statistics. Furthermore, values of VI and dRVI are extracted in MS Excel format for concurrent correlation analysis.

Considering the SAR data, two statistical tests are performed. The first considers the statistical mean metric from correlation with productivity crop parameters by the closest SAR measurements around the reference in-situ date. The second test considers standard deviation and variance metrics.

The concurrent correlation analysis, which aims to statistically determine the most suitable VI for monitoring phenology development of organic barley by means of remote sensing methods, was conducted in MS Excel. It is assumed that a Pearson’s correlation coefficient (*r*) in the range of 0 to 0.33 indicates a weak correlation, 0.34 to 0.66 indicates a moderate correlation, and 0.67 to 0.99 indicates a strong correlation [20].

Results and Discussion

Figure 6 represents the correlations of GCVI, SR, OSAVI, and EVI2 with the performance elements in phase BBCH-41. From the figure, it is observed that all four VI are highly correlated with the productivity parameters, such as Plant height (cm), Number of spike-like stems per m^2, as well as the Number of grains per spike. All that shows the suitability of S2 in the production monitoring of organic barley.

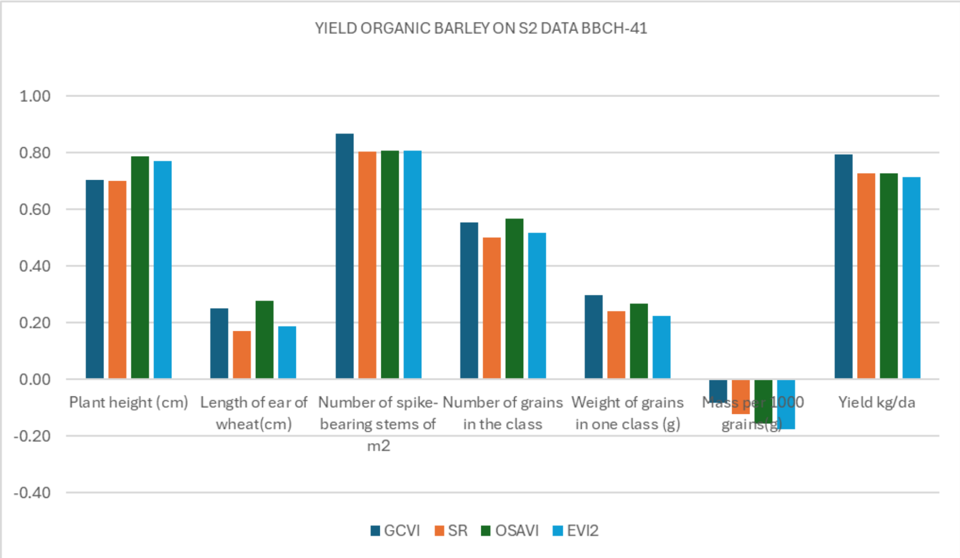

Fig. 6. Correlation of organic barley parameters with S2 data in phase BBCH-41

Figure 7 represents the results of the correlation analysis between the mean dRVI values calculated from S1. The index was correlated with the BBCH-30, 41, 51, and 77 phases. It is clear from the figure that the dRVI index has a strong negative correlation with yield, but only during the last BBCH-77 phase. In addition, the index also shows a strong negative correlation with the Number of spike-bearing stems of m^2. That gives us the reason to conclude that we can use the dRVI index for better monitoring of the plant when the crop enters the final phase of its development.

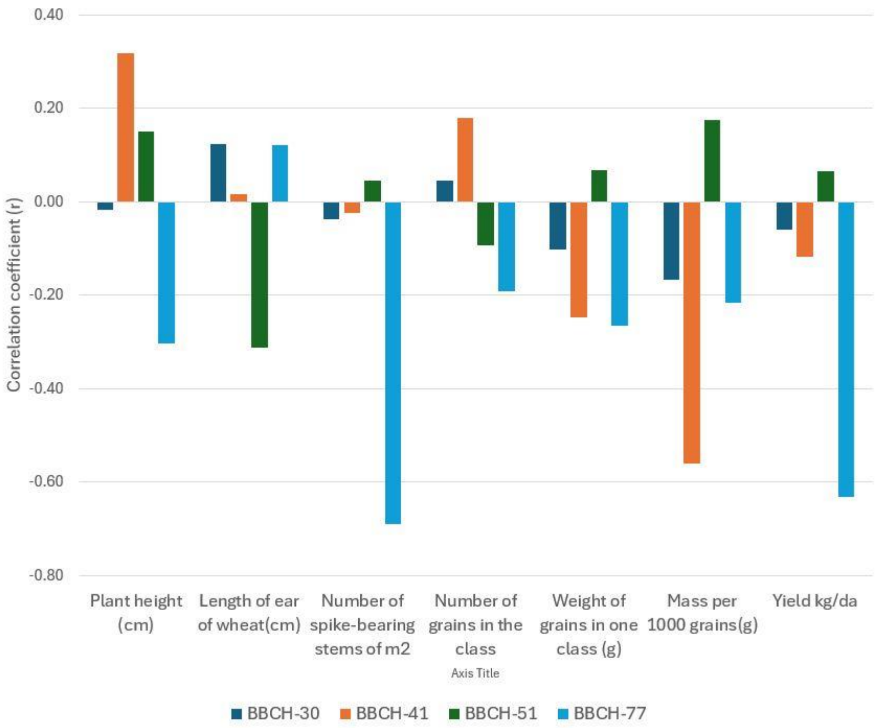

Fig. 7. Correlation of organic barley parameters with Sentinel-1 mean values

Figure 8 represents the result of the correlation analysis between the standard deviation of the distribution of dRVI values in the sampling buffer region of the in-situ data. In the analysis of the data, it is found that the standard deviation shows very good correlation with the yield in the phases BBCH - 41 and 51, which are critical phases of the crop development. This is explained by the fact that the volumetric scattering increases with the development of the crop, which implies a greater variation of the values in the statistical average region. A growing correlation convergence with the development of the crop and the standard deviation of dRVI is also observed, which is also proven by the high correlation dependence with the Number of spike-bearing stems of m^2.

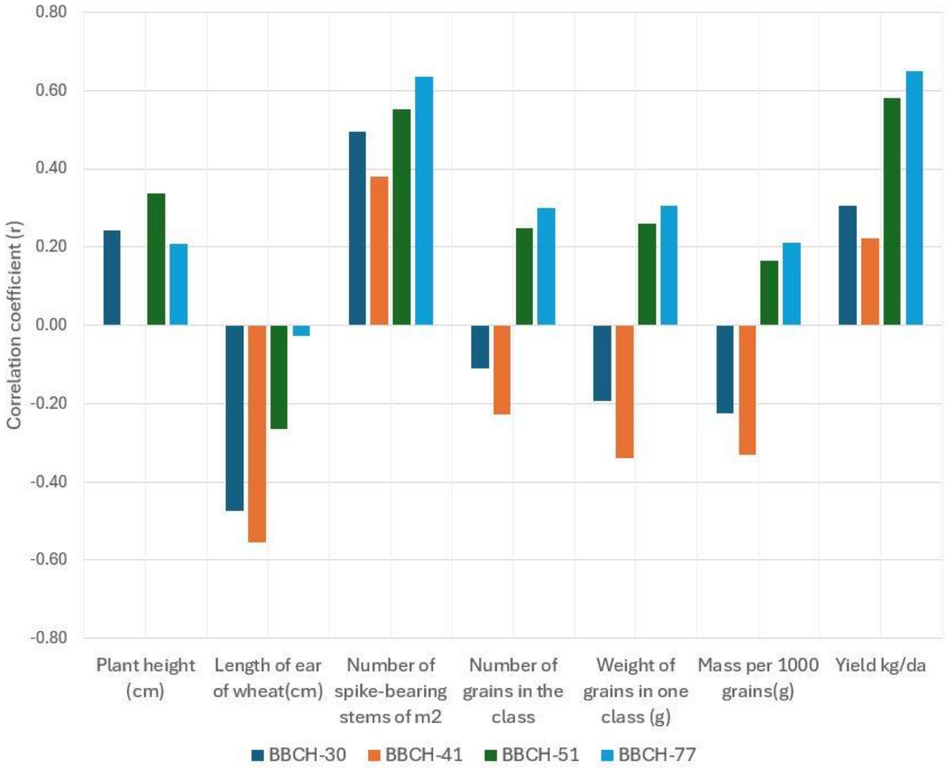

Fig. 8. Correlation of organic barley parameters with S1 data on standard deviation

Conclusion

From the conducted analysis, it can be concluded that the S2 optical data are more suitable for the objective of the study, as these data allow monitoring the yield of organic barley with multiple vegetation indices (VI) during most vegetation phases. The radar data obtained from S1 complements the analysis for the monitoring of the organic barley crop while also providing yield information. In spite of this, the dRVI radar vegetation index is shown to be sensitive to crop development. This allows us to use this VI to determine when a crop has entered the final phase of its development.

Acknowledgements

This work was supported by the Bulgarian Ministry of Education and Science under the National Research Programme “Young scientists and postdoctoral
students - 2” approved by DCM 206 / 07.04.2022. The organic certification

company Balkan Biosert Ltd. connects them with the organically certified farmer, Borislav Slavchev, in the village of Byala Reka, municipality of Parvomay. They also extend their thanks to the organically certified farmer Borislav Slavchev, from the village of Byala Reka, where the field campaign took place.

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СРАВНЯВАНЕ НА ДВА ТИПА САТЕЛИТНИ ДАННИ, ОПТИЧНИ ОТ SENTINEL-2 И РАДАРНИ ОТ SENTINEL-1 SAR ЗА ПРИЛОЖИМОСТТА ИМ ЗА ПРЕДСКАЗВАНЕ НА ДОБИВА ОТ БИОЛОГИЧЕН ЕЧЕМИК

М. Чанев, Зл. Димитров

Резюме

Селскостопанските култури от ечемик са широко използвани в икономическия живот на човечеството и се характеризират с голяма екологична пластичност. Поради добрите си показатели, ечемикът е конкурент на

другите зърнени култури и е изключително подходящ за отглеждане в биологичното земеделие. Мултиспектралните данни от Sentinel-2, получавани по програма КОПЕРНИК (COPERNICUS) на ЕС, са доказали своята приложимост при мониторинга на земеделските култури в многобройни научни изследвания. Тези данни са безценни за оптимизиране на производствените процеси, включващи този вид култура. Целта на настоящото изследване е анализ на приложимостта на сателитните данни по програма КОПЕРНИК на ЕС на двата типа сателитни данни за мониторинг и прогнозиране на добива от биологично отглеждан ечемик. Направено е сравнение между сателитни данни, получени от оптични сателитни сензори от мисията Sentinel-2 и от радарни сателитни сензори тип SAR от мисията Sentinel-1. Проучена е тяхната статистическа връзка с добива на биологично отглеждан ечемик. Пространствената разделителна способност на всички изходни продукти от сателитните данни е 10 m. Установихме, че Фазата BBCH-41 се оказва най-подходяща за използването на оптичните данни от Sentinel-2 с цел генериране на различен набор от вегетационни индекси за прогнозиране на биологичния добив от културата ечемик, отглеждана в условията на биологично земеделие. В този аспект най-голяма приложимост показва Зеленият хлорофилен вегетационен индекс индекс (GCVI), който има най-висока корелация с добива, където коефициента на Пиарсън е ($r = 0.80$). При разглеждане на радарните данни от SAR, е изчислен Радарният вегетационен индекс в двойна поляриметрия (dRVI) в няколко времеви периода по време на вегетация на културата. Като е докладвано и в други изследвания, се наблюдава корелация между dRVI и нормализирания разликов вегетационен индекс по оптични данни (NDVI). Наблюдава се, че всички изходни SAR продукти са чувствителни към геометричните свойства на културата и в различна степен отразяват фенологичното развитие на разглеждания ечемик отглеждан в условия на биологично земеделие. В този контекст радарните данни от SAR допълват оптичните такива, като предоставят надеждна информация за фенологичното състояние на земеделските култури.