Journal of Applied Life Sciences and Environment
https://jurnalalse.iuls.ro

USV 1842

Article
https://doi.org/10.46909/alse-591210
Vol. 59, Issue 1 (205) / 2026: 187-200

COPERNICUS DATA SPACE ECOSYSTEM AND ITS RELEVANCE FOR DIGITAL AGRICULTURE IN ROMANIA

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Received: Jun. 04, 2026. Revised: Jun. 23, 2026. Accepted: Jul. 14, 2026. Published online: Jul. 17, 2026

ABSTRACT. This study presents a descriptive and exploratory analysis of the Copernicus Data Space Ecosystem (CDSE) and proposes a reproducible proof-of-concept workflow for its use in digital agriculture in Romania. The novelty lies not in a new algorithm or empirical validation but in the systematic documentation of an open-access workflow that links data discovery, visualisation, and the filtering and download of Sentinel-2 products with two locally relevant applications: Normalised Difference Vegetation Index-based crop monitoring and Normalised Difference Water Index-based surface water observation over a small inland reservoir in Iași County. The methodological approach consisted of a qualitative functional analysis of the platform, the identification of data categories relevant to agricultural applications, and the documentation of a structured workflow integrated into didactic and applied activities in agricultural engineering. Analysis showed that the platform provides accessible support for using Sentinel-2 multispectral imagery and derived vegetation and water-monitoring products in crop condition assessment, spectral index interpretation, and local resource monitoring. The education dimension is reported on the basis of classroom observations accumulated over three academic years. No formal assessment instrument was applied; thus, observations concerning student performance and digital competencies should be regarded as exploratory. Within these limits, the findings indicate that CDSE functions as an operational gateway for satellite data use and as a candidate support environment for academic training in digital agriculture in Romania.

Keywords: agricultural monitoring; Earth observation; geospatial data access; remote sensing education; Sentinel-2.

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Cite: Butnaru, C.L.
Copernicus Data Space Ecosystem and its relevance for digital agriculture in Romania.
Journal of Applied Life Sciences and Environment **2026**, *59* (1), 187-200.
https://doi.org/10.46909/alse-591210

INTRODUCTION

Digital agriculture relies increasingly on timely, cost effective spatial information capable of supporting crop monitoring, environmental assessment, and data driven farm management. Satellite remote sensing, particularly when combined with cloud based processing environments and complementary digital tools, has become a central component of modern precision agriculture, enabling applications such as crop mapping, yield estimation, and multi scale monitoring of vegetation condition (Chen *et al.*, 2023; Felegari *et al.*, 2021; Xing *et al.*, 2026).

Within this framework, the European Copernicus programme provides a major operational foundation through open access satellite imagery, environmental information services, and processing infrastructures designed for a wide range of agricultural and environmental applications (Buontempo *et al.*, 2020; Kussul *et al.*, 2025). In particular, the Copernicus Data Space Ecosystem extends the practical usability of Earth observation data by enabling integrated access, visualization, filtering, and cloud based processing of Sentinel products in a single digital environment (Fernández *et al.*, 2024; Kovács *et al.*, 2026).

In Romania, access to Copernicus satellite data and its derived products has become technically straightforward through the Copernicus Data Space Ecosystem (CDSE) platform; however, the systematic integration of these resources into agronomic education and applied farm research remains limited. The potential of Sentinel-2 imagery for crop monitoring and vegetation assessment has been partially explored at the national level, but structured workflows adapted to university teaching and experimental agriculture are still scarce (Butnaru, 2025).

Recent practical experience in developing laboratory guidelines for precision agriculture and presenting remote sensing results at international symposia suggests that a structured, accessible approach to Earth observation data can support teaching and applied research at Romanian agricultural universities (Butnaru, 2024, 2025).

Against this background, the present study adopts a descriptive and exploratory design and does not test confirmatory hypotheses.

Its scientific contribution is to propose, document, and illustrate a reproducible, open-access workflow based on CDSE that links data discovery, visualisation, and the filtering and download of Sentinel-2 products with two locally relevant use cases in Romanian digital agriculture: Normalised Difference Vegetation Index (NDVI)-based crop monitoring of agricultural parcels in Iași County and Normalised Difference Water Index (NDWI)-based observation of surface water dynamics over the Pârcovaci reservoir.

Although CDSE already exists, no Romanian-language or Romania-specific workflows that are currently available in the peer-reviewed scientific literature have been documented or tested for their use in agronomic teaching and applied research, constituting a practical barrier to its wider adoption. Therefore, peer-reviewed documentation is justified to make such a workflow citable, archivable, and reproducible for the national context.

Accordingly, the study is guided by two research questions: (RQ1) to what extent can the CDSE Browser be used by Romanian agricultural students and researchers to access and visualise Sentinel-2 data and derived spectral indices without specialised desktop software or paid subscriptions; and (RQ2) what are the practical barriers to integrating an open-access Earth Observation platform, such as CDSE, into laboratory teaching in a Romanian agronomic faculty.

To address these questions, this study pursues three supporting objectives: (i) to describe the functional architecture of CDSE relevant to agricultural and environmental monitoring; (ii) to document a step-by-step proof-of-concept workflow for accessing and using Sentinel-2 derived products through the CDSE Browser, formulated so that it can be replicated by other Romanian users without specialised software or paid subscriptions; and (iii) to report, in an exploratory manner, the experience accumulated over three academic years and integrate this workflow into university-level teaching of precision and digital agriculture.

Consistent with its descriptive and exploratory nature, this study does not aim to demonstrate, validate, or quantify any pedagogical effect. Statements regarding educational use are based on classroom observations rather than formally collected and analysed educational data, and any future claims of pedagogical effectiveness require dedicated assessment instruments that are beyond the scope of the present work.

MATERIALS AND METHODS

Study approach

This study used a qualitative functional analysis of CDSE to evaluate its relevance for digital agriculture applications and university-level agronomic training. The analysis was based on three years of direct practical experience with the platform, accumulated through applied research and laboratory teaching activities in Digital Agriculture and Precision Agriculture courses. The analysis focused on the practical usability of the platform for accessing, visualising, filtering, and processing Earth observation data relevant to crop, vegetation, and water monitoring. CDSE was selected because it provides open access to Copernicus Sentinel data and integrates multiple tools for browsing, downloading, and cloud-based analysis in a single digital environment.

Platform description and data sources

CDSE is the official open-access platform of the European Copernicus Programme, launched in January 2023 as a successor to the Copernicus Open Science Hub. The platform provides free and instant access to the full archive of Sentinel satellite imagery, Copernicus Land Monitoring Service products, and complementary datasets. CDSE integrates data discovery, visualisation, filtering, downloading, and cloud-based processing in a single digital environment, reducing the need for local data-storage and processing infrastructure and lowering the technical barriers associated with access to Earth observation data. Recognising its immediate relevance for agricultural education, this platform was incorporated into university-level teaching activities as early as 2024, within one year of its official launch, through a dedicated laboratory guidebook published for the Precision Agriculture practical course (Butnaru, 2024).

The laboratory guidebook (Butnaru, 2024) is a didactic Romanian-language resource that presents the practical steps of the workflow for classroom use, and the present manuscript provides the first peer-reviewed, citable, and archivable documentation of that workflow and contains its conceptual framing, two locally relevant application cases, and a critical discussion of its operational and educational limitations. Therefore, the two outputs are complementary rather than overlapping, with the guidebook serving internal teaching and this article making the workflow reproducible and verifiable in the scientific literature.

The primary data source used in this study is the Sentinel-2 MultiSpectral Instrument (MSI), accessed through CDSE. Sentinel-2 acquires data in 13 spectral bands spanning the visible, near-infrared, and short-wave infrared regions at 3 spatial resolutions (10 m for visible and near-infrared bands B2, B3, B4, and B8; 20 m for the red-edge and short-wave infrared bands; and 60 m for atmospheric-correction bands), with a swath width of 290 km and a revisit time of approximately 5 days at the equator using twin satellites Sentinel-2A and Sentinel-2B. Products are distributed at two processing levels: Level-1C (top-of-atmosphere reflectance) and Level-2A (bottom-of-atmosphere, atmospherically corrected surface reflectance). All analyses in this study used Level-2A products, which are available through the CDSE Browser.

Workflow for spectral index visualisation and data extraction

The analytical workflow consisted of six sequential steps performed in the CDSE Browser interface.

First, user registration and authentication were completed on the CDSE portal, providing access to the full Sentinel-2 archive and all available visualisation layers.

Second, the area of interest (AOI) was defined by drawing a polygon circumscribing the target agricultural or water monitoring zone on the interactive map. The AOI boundary was used for the spatial filtering of available imagery and constraining the visualisation to the relevant geographic extent.

Third, satellite acquisitions were filtered by date and maximum cloud cover threshold (≤30% for exploratory visualisation; ≤2% for quantitative assessment), and the desired spectral index layer was selected from the pre-configured layer library. The layers applied in this study included the following: NDVI (*Equation 1*), introduced by Rouse *et al*. (1973); NDWI (*Equation 2*), proposed by McFeeters (1996); and the True Colour composite (Red B4, Green B3, Blue B2), as presented in *Table 1*.

$$NDVI = \frac{NIR - R}{NIR + R} \tag{1}$$

$$NDWI = \frac{GREEN - NIR}{GREEN + NIR} \tag{2}$$

The final steps consisted of visualising and interpreting these indices in the browser and exporting GeoTIFF products for subsequent analysis in desktop GIS.

The entire workflow, as illustrated in *Figure 1*, from platform access to spectral index interpretation, was documented and integrated into the laboratory guidebook for the Precision Agriculture course at the Faculty of Agriculture, “Ion Ionescu de la Brad” Iași University of Life Sciences, constituting Practical Work no. 9 of the guidebook (Butnaru, 2024). Within the structure of that guidebook, the present Earth observation exercise (Practical Work no. 9) follows eight practical works covering introductory GIS and precision agriculture topics, so that students reach the CDSE workflow only after acquiring the necessary spatial data fundamentals.

Functional analysis criteria

The platform was evaluated according to three main criteria. The first criterion was usability, referring to the ease with which a user can define an AOI, select a time interval, filter scenes, identify suitable products, and export results. The second criterion was thematic relevance, referring to the degree to which the available products support digital agriculture tasks, such as crop monitoring, vegetation assessment, and water-related environmental observations. The third criterion was educational and applied integration, referring to the extent to which the platform can be incorporated into laboratory classes, student projects, and small-scale research activities in agronomic higher education.

Considered workflows

Three representative workflows were examined to evaluate the practical utility of CDSE. The first workflow addressed the identification and visualisation of Sentinel-2 imagery for NDVI-based crop monitoring.

Table 1 – Sentinel-2 L2A spectral bands, wavelengths, and derived indices applied in the CDSE workflow

Index	Formula	Bands used (Sentinel-2)	Wavelengths (nm)	Spatial resolution (m)
True Colour	Red (B4), Green (B3), Blue (B2) composite	B4 (665 nm)	B3 (560 nm) / B2 (490 nm)	10
NDVI	(NIR − Red) / (NIR + Red)	B8 (NIR) and B4 (Red)	842 (B8), 665 (B4)	10
NDWI	(Green − NIR) / (Green + NIR)	B3 (Green) and B8 (NIR)	560 (B3), 842 (B8)	10

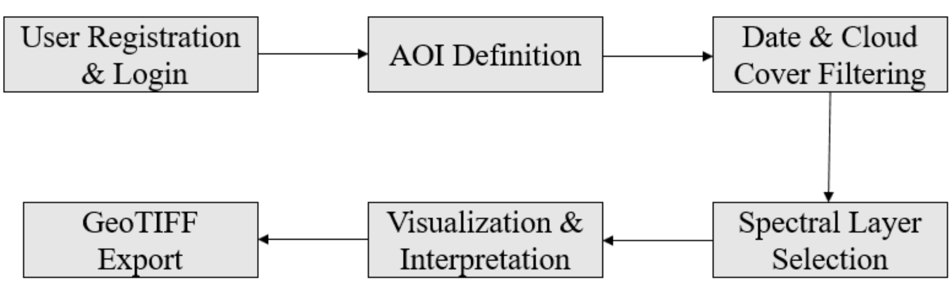

Figure 1 – Workflow for spectral index visualization and data extraction using the CDSE Browser interface

The second workflow focused on the interpretation of optical imagery for water-related observation, including the use of NDWI for assessing the extent of surface water. The third workflow concerned the integration of the platform into university laboratory activities through live demonstrations and guided student interactions with the Copernicus Browser interface.

Scope and limitations

The present study did not aim for the large-scale quantitative validation of satellite-derived indicators. Instead, it examined the operational and educational potential of CDSE as an accessible environment for Romanian digital agriculture, emphasising practical use cases and reproducible introductory workflows. This approach was considered appropriate because the objective of this paper was to assess platform relevance, not to compare algorithmic performance across multiple remote sensing systems. Given the qualitative nature of functional analysis, conventional measures of statistical variability are not applicable to the present study.

With respect to the educational component, the observational basis of this study must be explained, as no systematic data collection, assessment instrument, rubric, pre-test, or post-test was performed and no control group was used. All statements concerning student performance are informal teaching reflections accumulated over three academic years (approximately 120 undergraduate and 60 Master's students in total) and should be interpreted as exploratory observations rather than as measured pedagogical outcomes.

RESULTS

Platform usability

The registration and authentication process on the CDSE portal was completed without significant difficulties by the instructor and students. The interface was intuitive, and no technical barriers were encountered during the login procedure. The definition of the AOI represented a more challenging step, particularly for students unfamiliar with the geographic location of the target parcels. To overcome this limitation, a combined approach was adopted. Parcels were first located using Google Maps, after which the geographic coordinates were extracted and entered into the CDSE Browser interface. This two-step localisation procedure proved effective and was adopted as a standard practice during laboratory activities. Date and cloud cover filtering were assessed as highly intuitive. However, the cloud cover itself represented a significant practical limitation. Even at cloud cover thresholds of 15–20%, the visibility of surface features was frequently insufficient for reliable spectral index interpretation, reducing the number of usable acquisitions available for a given time interval.

Thematic relevance for digital agriculture

The CDSE Browser provided access to pre-configured spectral index layers relevant to agricultural and environmental monitoring. The NDVI layer (*Figure 2*) enabled visualisation of the condition of the vegetation over agricultural parcels, identifying spatial variability in crop development within the browser interface.

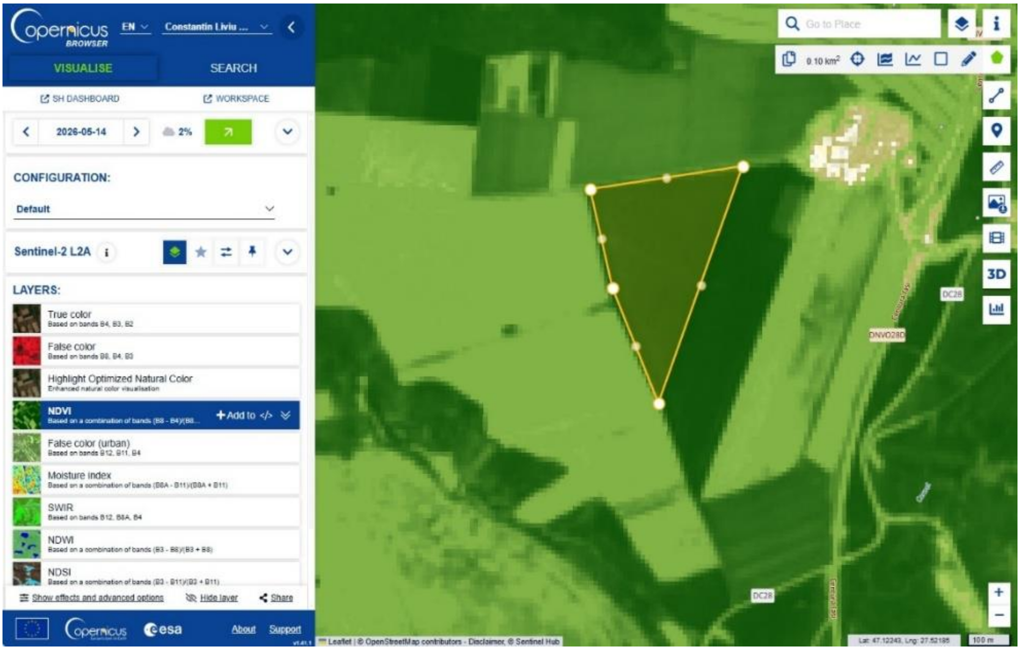

Figure 2 – Visualisation of the Normalised Difference Vegetation Index (NDVI) layer over an agricultural parcel using the Copernicus Browser interface and Sentinel-2 L2A imagery, Iași County, Romania

The NDWI layer (*Figure 3*) enabled the visualisation of the extent of surface water over small inland water bodies, demonstrating the platform's applicability for water-related environmental observation on a local scale.

Educational and applied integration

The CDSE workflow was tested by undergraduate students enrolled in the fourth year of the Agriculture programme (Precision Agriculture course, approximately 20 students per group) and first-year Master's students (Digital Agriculture course, approximately 20 students per group).

Internet connectivity represented the primary technical obstacle at both levels. The CDSE platform hosts more than 80 petabytes of online Earth observation data, and each visualisation request requires the streaming and partial downloading of high-resolution satellite imagery directly to the user's device. Consequently, when all students in a laboratory group accessed the platform simultaneously through a shared network router, loading speeds were significantly reduced, compromising the continuity of the practical exercise. As a partial solution, mobile hotspot connections were used, with the majority of students (an informal classroom estimate of 8 of 10) having this capability; this figure was estimated rather than formally counted.

Based on direct classroom observation over three academic years, the majority of fourth-year undergraduate students completed the workflow independently, and a smaller proportion required peer or instructor support.

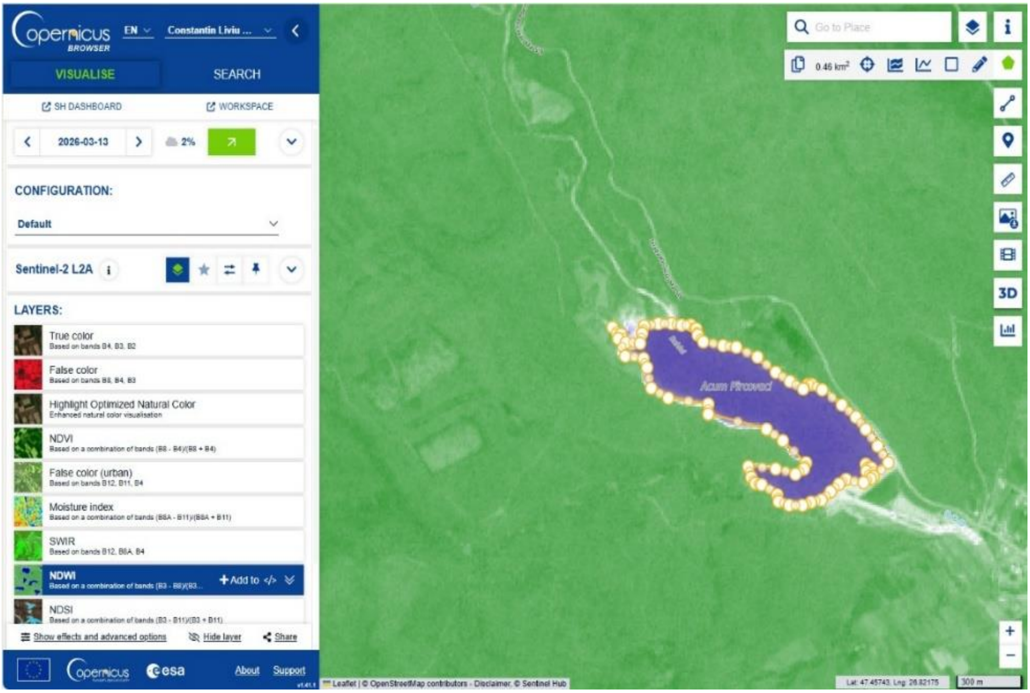

Figure 3 – Visualisation of the Normalised Difference Water Index (NDWI) layer over the Pârcovaci reservoir using the Copernicus Browser interface and Sentinel-2 L2A imagery, Iași County, Romania

These descriptors are informal observational impressions and are not derived from any formal assessment instrument; therefore, any apparent proportion should be read as an approximate qualitative estimate rather than as a measurement.

Based on these classroom observations, the CDSE platform was technically accessible to undergraduate and Master's students, but its practical usability in laboratory settings depended on both network infrastructure and the prior digital competencies of the students.

These remarks should be regarded as exploratory observations from teaching practice, as no formal assessment instrument was applied; consequently, no claim is made here regarding the measured improvements in digital competencies or pedagogical effectiveness.

DISCUSSION

The results of the qualitative functional analysis are consistent with the descriptive and exploratory aim of this study and indicate that CDSE can be used as an accessible and operationally relevant entry point to Earth observation data for digital agriculture in Romania. Within the limits of this design, the present contribution does not claim to demonstrate platform effectiveness but rather documents a tested proof-of-concept workflow that links data access, spectral index visualisation, and downloading with two locally relevant use cases (NDVI-based crop monitoring and NDWI-based observation of an inland reservoir) and that has been integrated into university teaching practice in a Romanian agronomic faculty.

From a usability perspective, the registration and authentication process was straightforward, consistent with the design objectives of CDSE as a platform built to serve users ranging from beginners to advanced researchers in a single digital environment (Kovács *et al*., 2026).

The supplementary use of Google Maps for parcel localisation prior to AOI definition was an effective and practical solution, demonstrating that minor workflow adaptations can successfully compensate for geospatial orientation limitations among agricultural students and practitioners.

Cloud cover filtering was assessed as intuitive, but atmospheric conditions remain an external constraint inherent to optical remote sensing in temperate climates, independent of the platform itself. This limitation has been well documented in the literature, as cloud contamination affects the availability of usable Sentinel-2 acquisitions across multiple agricultural monitoring applications (Chen *et al*., 2023; Felegari *et al*., 2021).

In terms of thematic relevance, the NDVI and NDWI layers available in the CDSE Browser demonstrated an applicability for crop condition assessment and surface water monitoring, respectively. NDVI-based visualisation supported observations consistent with previous findings on vegetation dynamics under Romanian conditions (Butnaru, 2025), confirming that Sentinel-2 derived indices effectively capture spatial variability in crop development on the field scale. Similar conclusions regarding the reliability and agricultural applicability of NDVI derived from Sentinel-2 have been reported across crop types and geographic contexts, including studies combining Sentinel-1 and Sentinel-2 data for crop mapping (Felegari *et al*., 2021), multi-sensor NDVI time series construction for crop monitoring (Chen *et al*., 2023), and vegetation index assessment for land consolidation estimation (Kocur-Bera and Małek, 2024). The potential of Sentinel-2-derived NDVI has also been evaluated in comparison to UAV-based multispectral platforms in vineyard monitoring studies, in which satellite-derived indices have demonstrated comparable performance to proximal sensing approaches under favourable atmospheric conditions (Sozzi *et al*., 2020; Vélez *et al*., 2023).

Furthermore, the availability of high-resolution vegetation phenology products within the Copernicus ecosystem, such as the HR-VPP datasets evaluated by Prikaziuk *et al*. (2025), extends the analytical potential of CDSE beyond single-date index visualisation toward continuous seasonal monitoring of crop development.

Sentinel-2 and complementary Copernicus data have been used to map land cover and agronomic classes through NDVI and NDRE stacks in geomorphologically complex regions (Orusa *et al*., 2023a) and predict land-cover changes with Copernicus Earth observation data in support of territorial planning (Orusa *et al*., 2026). Google Earth Engine workflows have enabled the mapping of phenological metrics from combined Landsat and Sentinel-2 collections (Orusa *et al*., 2023c). Together, these studies illustrate the analytical breadth of the Sentinel-2 record, which CDSE makes openly accessible.

The NDWI-based visualisation of small inland water bodies aligns with approaches reported in the literature for reservoir and surface water monitoring using Sentinel-2 imagery (Ghansah *et al*., 2022; Perin *et al*., 2021).

The challenge of cloud-induced data gaps in an optical surface water time series, addressed through gap-filling methodologies applied to Landsat and Sentinel data (Bai *et al*., 2022), further highlights the importance of cloud cover management in operational water monitoring workflows, a limitation equally relevant in CDSE-based applications.

The broad scope of CDSE data collections, encompassing Sentinel missions alongside contributing missions and Copernicus service products, positions the platform as a comprehensive resource for multi-scale agricultural and environmental monitoring, as demonstrated by its application in national-level land use mapping in Ukraine (Kussul *et al*., 2025) and its integration with the Copernicus Climate Change Service for agriculture (Buontempo *et al*., 2020).

The same open-access Earth observation data and cloud-processing paradigm underlie a wide range of operational applications beyond crop monitoring, including remote sensing-supported sustainable agriculture and post-crop biomass mapping for grazing (Sarvia *et al*., 2026), land-surface temperature and climate-exposure assessment (Orusa *et al*., 2023b; Orusa and Borgogno-Mondino, 2021), and One Health and wildlife disease surveillance that integrates GIS and remote sensing (De Petris *et al*., 2025); this diversity of EO applications highlights the value of consolidating data discovery, visualisation, and processing in a single open environment, such as CDSE.

Concerning educational and applied integration, three academic years of teaching practice with the proposed workflow suggest that CDSE can be used to enrich the applied dimension of agricultural education at the Faculty of Agriculture in Iași.

In our teaching practice, the documented workflow enabled the majority of fourth-year undergraduate students and a higher share of Master's students to carry out introductory Earth observation tasks independent of specialised desktop GIS software or paid data subscriptions.

The approximate 70% figure reported in Section 3.3 is a qualitative observational estimate rather than the result of a structured assessment. Network connectivity and prior digital skills were the practical bottlenecks most often observed in class, and they were mitigated through mobile hotspot connections and the progressive structuring of laboratory tasks.

These observations indicate that CDSE is a credible candidate environment for supporting the development of digital competencies in Romanian agricultural universities, but the present study does not provide systematic evidence of such an effect. Dedicated studies based on validated questionnaires, pre- and post-tests, or competence rubrics are required to formally assess the pedagogical effectiveness.

Scope of the contribution and limitations

The present contribution has several limitations.

First, the study is descriptive and exploratory by design; it documents an open-access workflow and reports observational experience accumulated during its use, rather than testing a confirmatory hypothesis or quantifying outcomes.

Second, the educational dimension is exclusively based on classroom observations gathered over three academic years of Precision Agriculture and Digital Agriculture courses; no validated questionnaire, pre- and post-test, structured competence rubric, or comparable control group was employed. Consequently, any statements concerning students' digital competencies, perceived ease of use, or completion rates (including the approximate 70% reported in Section 3.3) must be interpreted as qualitative observational estimates and not as evidence of the measured pedagogical effectiveness.

Third, the applied analysis is geographically and thematically limited to two small case study areas in Iași County (agricultural parcels and the Pârcovaci reservoir) and two spectral indices (NDVI and NDWI). Therefore, it is not intended to generalise platform performance across regions, crops, or sensors.

Fourth, the analysis is restricted to the functionality of the current CDSE Browser used through a standard user account; advanced features, such as the Sentinel Hub APIs, openEO, and large-scale batch processing, fall outside the scope of this contribution. Future work should extend the proposed workflow toward a formal evaluation of its pedagogical effects through validated assessment instruments and toward quantitative multi-annual monitoring of crops and inland water bodies in Romania based on the long-term Sentinel-2 archive accessible via CDSE.

CONCLUSIONS

Within the descriptive and exploratory scope of this study, CDSE is a functionally accessible and thematically relevant open-access environment for digital agriculture in Romania.

The scientific contribution of this work is not a new empirical validation of CDSE but the systematic documentation of a reproducible proof-of-concept workflow that links data discovery, visualisation, and the filtering and downloading of Sentinel-2 products with two locally relevant use cases (NDVI-based crop monitoring of agricultural parcels and NDWI-based observation of the Pârcovaci reservoir in Iași County), formulated so that it can be adopted by other Romanian users without specialised software or paid subscriptions.

On the basis of three academic years of classroom observations, the integration of this workflow into laboratory courses suggests that structured open-access Earth observation activities can support the applied training of agronomic students. As no formal pedagogical assessment was performed in the present study, this observation is reported as exploratory teaching experience rather than as demonstrated evidence of improved digital competencies, and the main practical bottlenecks observed in class were network infrastructure and heterogeneous prior digital skills.

Future research should focus on quantifying the long-term effects of CDSE-based teaching on student digital competency development and exploring the potential of additional data collection available within the ecosystem, including Sentinel-1 SAR imagery and Copernicus Land Monitoring Service products, for expanding agricultural and environmental monitoring applications in Romania.

The long-term archive of Sentinel-2 imagery available in CDSE also offers perspectives for the multi-annual monitoring of inland water bodies, such as the Pârcovaci reservoir in Iași County, where monitoring surface water dynamics over extended periods could provide valuable insights into the relationship between climate variability and local water resource availability.

Author Contributions: Conceptualisation: LCB; Methodology: LCB; Software: LCB; Formal analysis: LCB; Investigation: LCB; Resources: LCB; Data curation: LCB; Writing - original draft: LCB; Writing - review and editing: LCB; Visualisation: LCB. The author has read and approved the published version of the manuscript.

Funding: There was no external funding for this study.

Acknowledgement: The author acknowledges the use of Perplexity AI as a language assistance tool during the preparation and English language revision of this manuscript.

Data availability statement: No new primary data were generated in this study. All Sentinel-2 satellite data used are publicly and freely available through the Copernicus Data Space Ecosystem (https://dataspace.copernicus.eu). Any additional materials supporting the documented workflow are available from the corresponding author upon reasonable request.

Conflicts of interest: The author declares no conflict of interest.

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Academic Editor: Dr. Ilie BODALE

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