GIS TECHNOLOGIES FOR SUSTAINABLE AGRICULTURAL LAND MANAGEMENT

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***Abstract**: The integration of GIS technologies in agriculture offers new opportunities for optimizing fertilization, irrigation and crop management. This paper explores the applicability of spatial analytics in agricultural land monitoring, using geospatial data to assess soil variability and plant health. The case study focuses on an agricultural holding in Eastern Romania, where differences in productivity and resource use efficiency are analyzed according to local conditions. By assessing the impact of data-driven decisions, the research provides practical insights for more sustainable and economically efficient agriculture.*

***Keywords:** GIS; precision agriculture; sustainability; agricultural management*

1. Introduction

Precision agriculture has become a fundamental tool in the transition towards a sustainable agricultural system adapted to new climatic, economic and technological challenges. This involves the integrated use of digital technologies to collect, analyze and interpret data with the aim of optimizing farm-level decisions.

Geographic Information Systems (GIS) enable the spatial representation of land and the integration of multi-source data - satellite imagery, field observations, historical maps - into a unified model for analysis and decision making. One of the most relevant tools used in this process is the Normalized Difference Vegetation Index (NDVI), a spectral index derived from satellite imagery that reflects photosynthetic activity and overall vegetation health [1,2].

Based on NDVI values, farmers can identify areas of stress in the crop and differentially intervene using technologies such as VRA (Variable Rate Application). This involves automatically adjusting the number of inputs applied (fertilizers, seeds, herbicides) according to the actual needs of each micro zone in the plot.

The OneSoil platform provides an affordable example of technology integration in agriculture. Using Sentinel-2 imagery and vegetation indices, it allows the monitoring of crop evolution and the generation of NDVI maps even without advanced equipment. In addition, the user can observe the dynamics of NDVI values over time and visually correlate crop performance with applied agronomic interventions.

This paper capitalizes on these resources to analyze a real plot located in Eastern Romania, using data from the OneSoil platform and information provided by the farmer. The aim is thus to highlight the real applicability of GIS technology in precision agriculture, even with minimal equipment and limited data set.

Relevance of the research topic in specialized literature: bibliometric analysis

In order to strengthen the theoretical background of the research and to validate the choice of topic, a bibliometric review of the literature on the application of GIS technologies, NDVI and variable application strategies (VRA) in precision agriculture was conducted. The main objective was to assess the current scientific interest in these directions and to identify dominant trends at the international level [15,19].

The search was conducted in two of the most important scientific databases - Scopus and Web of Science - limiting the search to articles and reviews published between 2010 and 2025. A complex expression constructed to reflect the intersection between precision agriculture, vegetation analysis and geospatial technologies was used:

TITLE-ABS-KEY (("NDVI" OR "normalized difference vegetation index" OR "vegetation index") AND ("GIS" OR "geographic information system" OR "spatial analysis" OR "remote sensing") AND ("precision agriculture" OR "smart farming" OR "site-specific management" OR "variable rate application" OR "VRA"))*

This expression was designed to exclusively extract relevant articles that explore the complementarity between vegetation (NDVI) analysis, GIS technologies and differentiated application strategies (VRA) in the context of the digital transformation of agriculture.

After applying the filtering, 661 papers were identified in Scopus and 679 in Web of Science, which, after removing duplicates in the RStudio environment using the Bibliometrix package, led to a final set of 680 unique articles. Analyzing these through the Biblioshiny interface provided a detailed insight into the evolution of the volume of research and the dominant thematic structure in the field [16].

The temporal distribution of publications (Fig. 1) shows a gradual increase in scientific interest starting in 2016 and culminating in 2024, reflecting the increasing focus on sustainable digital solutions in agriculture. However, compared to other related fields, the total number of papers remains relatively modest, indicating that the field, although emerging, is still insufficiently explored and requires further research, especially in the context of practical applicability at the farm level [17].

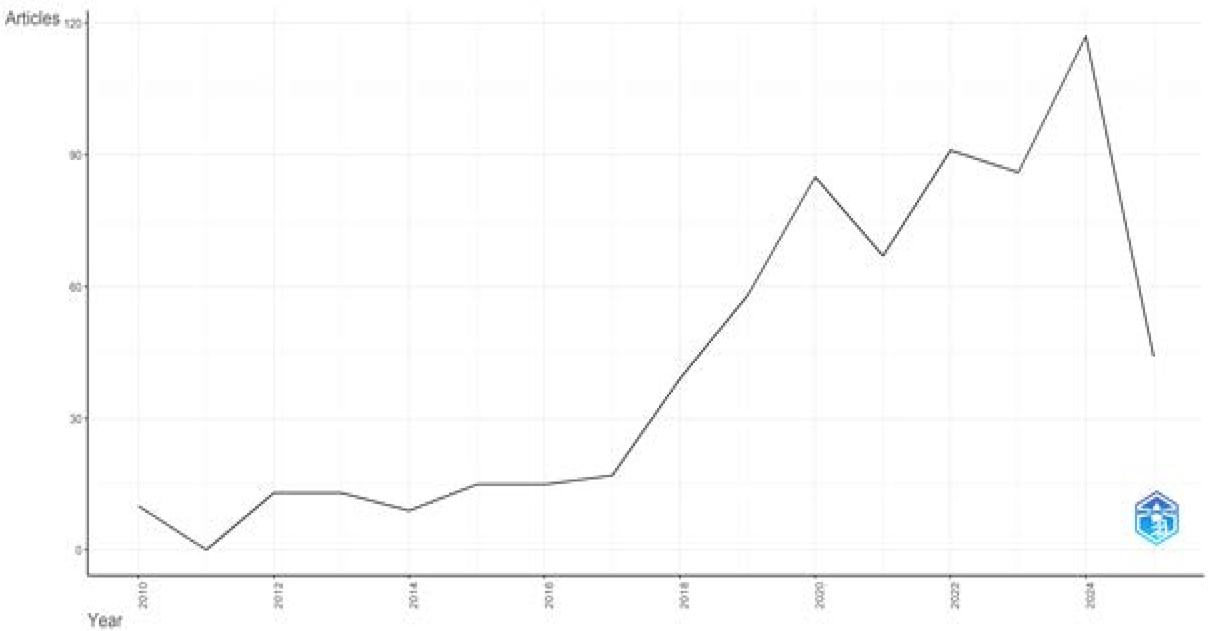

Fig. 1. Evolution of annual scientific publications (2010-2025)

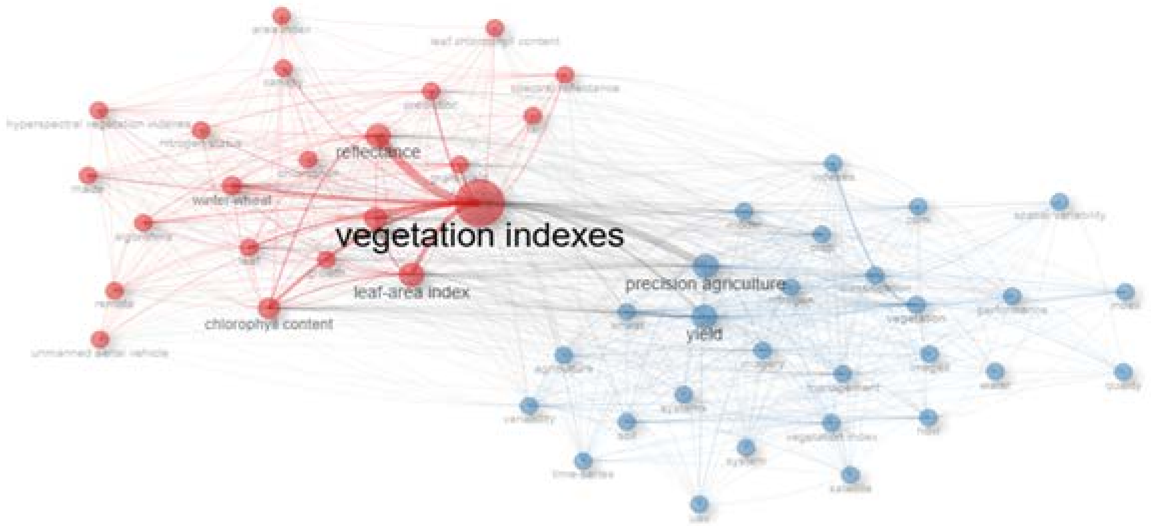

Fig. 2. Co-occurrence network of dominant keywords

The keyword co-occurrence network highlights a concentration of research in two major directions: an analytical axis, oriented towards the assessment of vegetation condition and the use of spectral indices (NDVI, reflectance, chlorophyll content), and an application axis, centered on agronomic decisions (yield, precision agriculture, soil variability). This duality reflects current efforts by the scientific community to build bridges between satellite data and operational decisions in the field [18].

The analyzed data confirm that the theme of the paper is in line with current research directions, while supporting the opportunity to continue the study in an applied manner, adapted to local conditions, and contributing to the expansion of the knowledge base in a field still in development.

2. Material and Method

2.1. Surface area description and data collection

The studied land is located in the outskirts of Slobozia Conachi, Galati County, in an agricultural area representative for south-eastern Romania, with chernozemic soils and an active agricultural history. The analyzed area was initially delimited in Google Earth Pro, using satellite images and contours identified on the basis of agricultural works visible in the field. The resulting .kml extension was then imported into OneSoil, where a preliminary geospatial analysis of the plots was performed by interpreting the NDVI index and simulating VRA maps.

The obtained vector contours were verified by comparing with data from a structured shapefile (.shp, .dbf, .shx,. prj) generated based on GPS tracks of agricultural machinery. This confirmed the exact overlap between the digital and field delineation, providing confidence in the accuracy of subsequent analysis.

In the OneSoil platform, the 2024 season was selected and the land was divided into fields according to the visual variations highlighted in recent satellite imagery. For each field, the distribution of plot-level NDVI values was analyzed, with a focus on identifying areas with unevenly developed vegetation. The NDVI is a spectral index derived from the reflectance of red and near-infrared radiation, widely used for the assessment of crop physiological condition. Within the OneSoil platform, it is automatically updated based on Sentinel-2 imagery and visually interpreted as thematic color maps [5,6].

In order to correlate satellite observations with the reality on the ground, a semi-structured interview was conducted with the farmer managing the analyzed plot. The discussion included questions on crop history, variety used, sowing and harvesting periods, fertilization regime and productivity obtained in the last three years. In addition, the farmer was presented with the NDVI maps generated in the platform to check whether they corresponded to the realities on the ground and to assess whether such analysis could support him in future decision-making.

Through this integrated approach, the aim is to assess the applicability of GIS technologies in the context of real agriculture, with a focus on the following research question:

"Can GIS technologies and spatial analysis tools, such as NDVI and VRA, contribute to a more sustainable agricultural management adapted to real field conditions?"

This question underpins the whole scientific approach and places the study in a framework oriented towards practical applicability and agricultural sustainability.

2.2. Principle of NDVI index calculation

Normalized Difference Vegetation Index (NDVI) is an important parameter in remote sensing used to assess vegetation health and density. According to Tucker (1979), NDVI is calculated using the formula:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \quad (1)$$

where:

- **NIR** = near-infrared reflectance (~0.76-0.90 µm)
- **RED** = reflectance in the red spectrum (~0.63-0.69 µm)

Healthy vegetation absorbs red light (RED) intensively for photosynthesis and strongly reflects near-infrared radiation (NIR), resulting in high NDVI values. NDVI values range from −1 to +1; values close to +1 indicate dense and healthy vegetation, while values near 0 suggest bare soil, sparse vegetation, or urban surfaces.

NDVI can be significantly influenced by various factors such as atmospheric conditions (fog, clouds, aerosols), soil type, and the solar incidence angle. As a result, data interpretation requires careful correction and contextual analysis.

2.3. Variable Rate Application (VRA)

Variable Rate Application (VRA) is a foundational practice in precision agriculture, enabling real-time adjustment of seeding, fertilizer, and pesticide rates based on spatial variability across the field. Recent reports show that VRA can significantly improve resource-use efficiency and reduce environmental impact.

Input layers used to generate VRA prescription maps typically include satellite or drone imagery, yield monitors, and soil sampling data. When integrated, these sources enable more precise input management, thereby enhancing productivity and sustainability.

Implementing VRA relies on specialized equipment and robust economic assessment. Studies confirm that success depends heavily on farm-specific technical capacities and careful cost–benefit analysis to ensure return on investment.

2.4. Platform used – OneSoil

Digital platform OneSoil was used for spatial plot analysis and input differentiation simulations. It is a web-GIS application, accessible online, which integrates multi-satellite data (in particular from the Sentinel-2 mission) and allows monitoring of agricultural crops through automatically calculated vegetation indices [9,10]

The platform offers a number of useful tools for farmers and researchers, including:

- Displaying NDVI values at specific time intervals;
- Generating vigor zones based on pixel analysis;
- Simulation of Variable Rate Application (VRA) for seeding and fertilization;
- Possibility to export the resulting maps in compatible formats (.shp, .pdf);
- Comparisons between different crop years and highlight performance relative to other users in the region.

Although the free version has limitations in terms of frequency of image updates or customization of input parameters, it provides sufficient functionality for relevant analysis at plot scale, with direct applicability in agronomic decision-making.

3. Results and Interpretation

3.1. Agricultural context – agricultural year 2023–2024

In the agricultural year 2023-2024, durum winter wheat was grown on the analyzed plot, using the variety AVENUE, known for its yield stability and tolerance to water stress. Sowing took place on October 15, 2023, and harvesting took place on July 10, 2024. The total area was 28.8 ha, and according to the information provided by the farmer, the crop averaged 9130 kg/ha under irrigated conditions [7].

The applied fertilization technology included three main steps. A complex fertilizer NPK 14-40-0 was used at sowing, at a dose of 250 kg/ha, which provides a high phosphorus content, essential in the early stages of vegetation for root and vascular development.

During the active vegetation period, nitrogen-based fertilization was carried out in two tranches. The first application was made at the resumption of vegetation, using 220 kg/ha of ammonium nitrate (AN 33.5%), with a rapid effect on stimulating leaf mass. The second tranche of 150 kg/ha consisted of a 30% nitrogen fertilizer with sulphur content, applied at the phenophase of swelling–ripening, to support protein synthesis and increase yield quality.

This fertilization scheme was adapted to the specific conditions of the plot and aimed to support uniform crop development, maximize yield and maintain balanced nutrition throughout the growing cycle [8]

3.2. NDVI analysis and differentiated application - March 2024

In order to assess the vegetative state of the crop at the time of resumption of active growth, the NDVI image of March 7, 2024, automatically generated by the OneSoil platform, was selected. This time coincides with the period of application of the first nitrogen fertilization tranche, which provides an optimal context for differentiated agronomic decision-making.

Analysis of the NDVI map reveals a clear within-plot variability, with values ranging from 0.39 to 0.53. Based on these thresholds, the area was divided into three vigor zones (Fig.3.):

- **Zone 1** (low NDVI: 0.39-0.46), representing 32.9% of the plot (9.5 ha);
- **Zone 2** (medium NDVI: 0.47-0.50), with 33.1% (9.5 ha);
- **Zone 3** (high NDVI: 0.51-0.53), with 34% (9.8 ha).

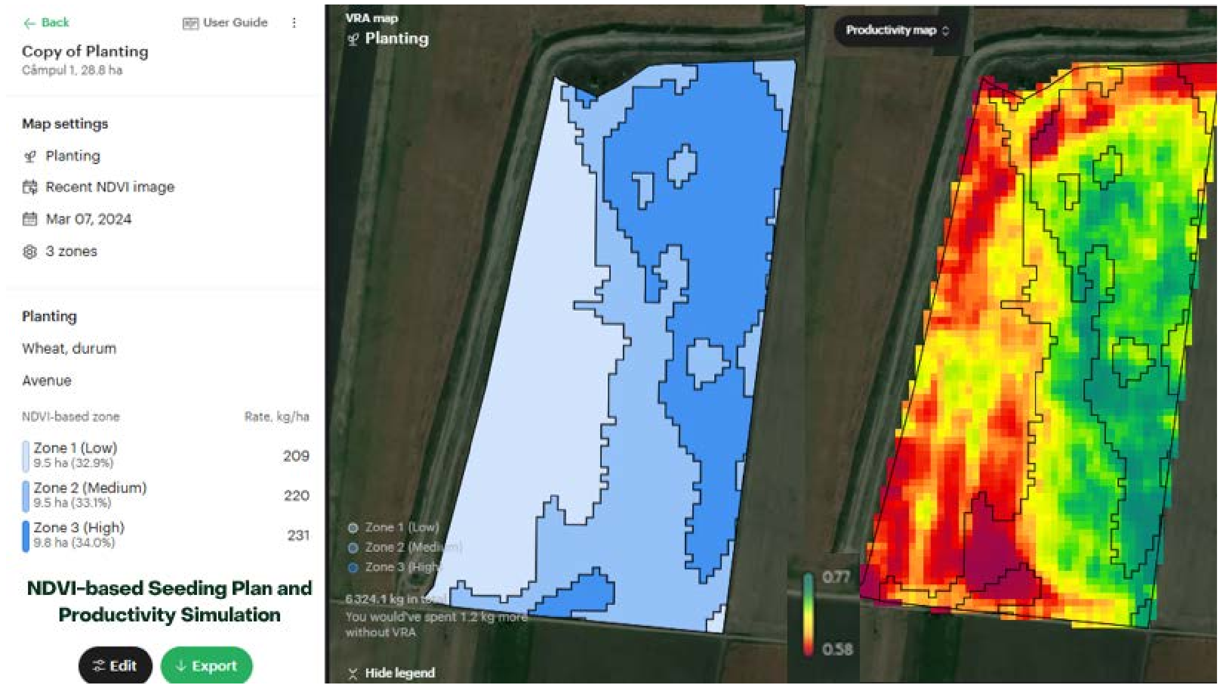

Fig. 3. NDVI values for March 7, 2024, with zonation thresholds determined in the OneSoil platform

The NDVI image generated in the OneSoil platform for March 7, 2024 shows significant differences in the vegetative condition of the crop. The index values range between 0.39 and 0.53, allowing the delineation of three zones with different vigor levels. These differences can be attributed to soil variability, crop density or the impact of over-winter climatic conditions.

The distribution of these zones is not random: the relief data indicate that the western and south-western parts of the field, where NDVI is lower, are located in depressional areas at altitudes between 97-100 m, with potential for water accumulation and poor aeration. This is also supported by the soil brightness map, which reports higher values in the same regions, suggesting soil exposure (sparse vegetation or stagnation in development).

Fig. 4. Soil Reflectance and Elevation Layers

Topographic analysis of the terrain shows that areas with low NDVI largely overlap with depression areas, suggesting problems related to drainage, water stagnation, or poor soil aeration, factors that can negatively affect plant growth [11].

The soil brightness image provides clues about vegetation cover. Areas with higher brightness coincide with those where NDVI is lower, suggesting partial vegetation cover or even lack thereof, possibly due to poor germination or other local factors.

Based on this assessment, a variable rate application (VRA) map was simulated for nitrogen fertilization (Fig.5). The recommended doses, based on NDVI, were:

- **195.8 kg/ha** in poor areas,
- **220 kg/ha** in average areas (standard value),
- **233.2 kg/ha** in vigorous areas.

Another hypothetical scenario was differential sowing, using a seed rate of (Fig.6):

- **209 kg/ha** in poor areas,
- **220 kg/ha** in average areas,
- **231 kg/ha** in good areas, where increased density can be supported by the soil and nitrogen input .

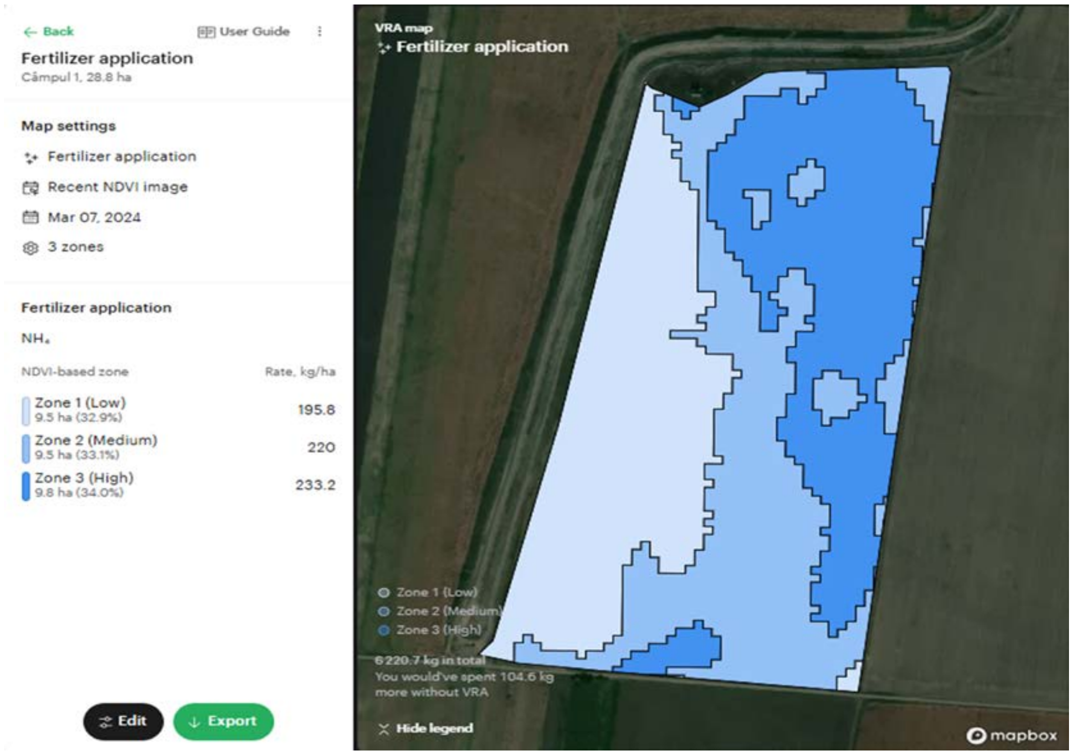

Fig. 5. Distribution of differentiated nitrogen fertilization doses according to NDVI.

This analysis confirms the usefulness of the NDVI index in the early identification of areas with poor development, enabling farmers to make tailored, data-driven decisions. However, NDVI does not provide a complete explanation; it needs to be supplemented with field observations and, ideally, agrochemical data (soil analyses, moisture surveys, N-sensor mapping, etc.). [12].

The differentiation of sowing density according to the vegetative state of the soil can be observed. Based on the NDVI analysis, a differentiated sowing scenario was simulated (Fig. 6), in which the seed density was adapted to the production potential of each area. This strategy can contribute to a more balanced distribution of plants, reducing competition in disadvantaged areas and making better use of fertile soils [13].

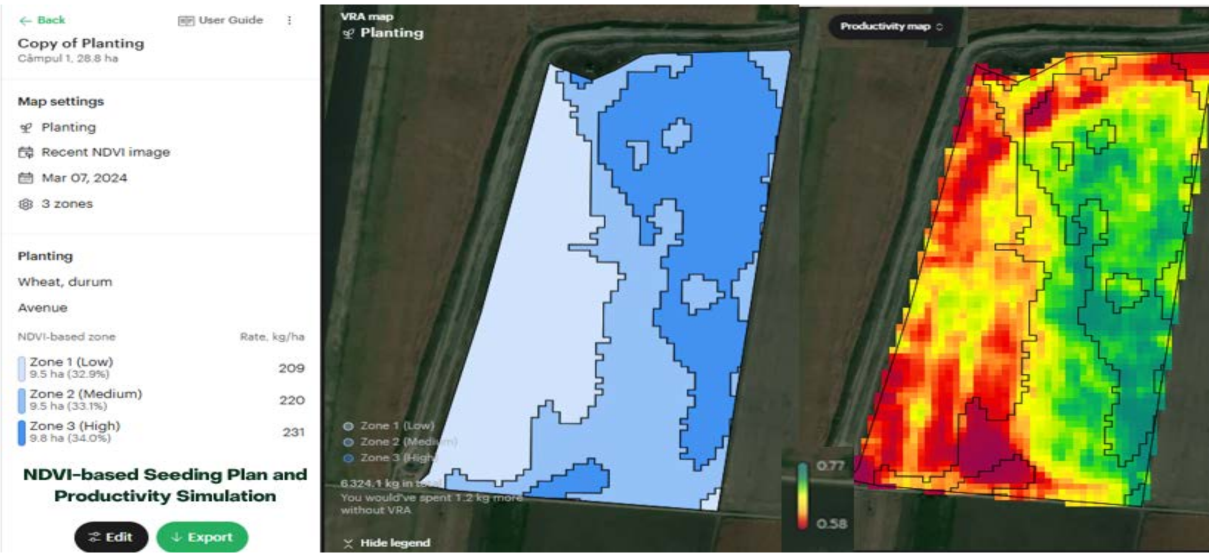

Fig. 6. NDVI based seeding plan and productivity simulation

To better understand the behavior of vegetation throughout the agricultural season, the evolution of the NDVI index in relation to climatic conditions was also analyzed. The seasonal graph generated by the OneSoil platform (Fig. 7) shows a gradual increase in NDVI starting in March, a peak in vegetation in April–May, and a progressive decline starting in June, associated with reaching physiological maturity.

At the same time, during the 2023–2024 agricultural season, 571 mm of precipitation accumulated, which can be considered an average amount for southeastern Romania. However, the farmer indicated that he resorted to irrigation, especially during April–June, which explains the high and constant NDVI index during the stages of straw elongation and grain filling. The average daily temperature also favored crop development, with over 3950 GDD (growing degree days) recorded, sufficient vegetation days in the range of +5°C to +30°C.

All these elements, NDVI, precipitation, temperature, and irrigation, contribute to a complete picture of the season, demonstrating that an integrated approach to satellite, pedoclimatic, and technology data can be a valuable tool in optimizing operational management decisions at the farm level [14].

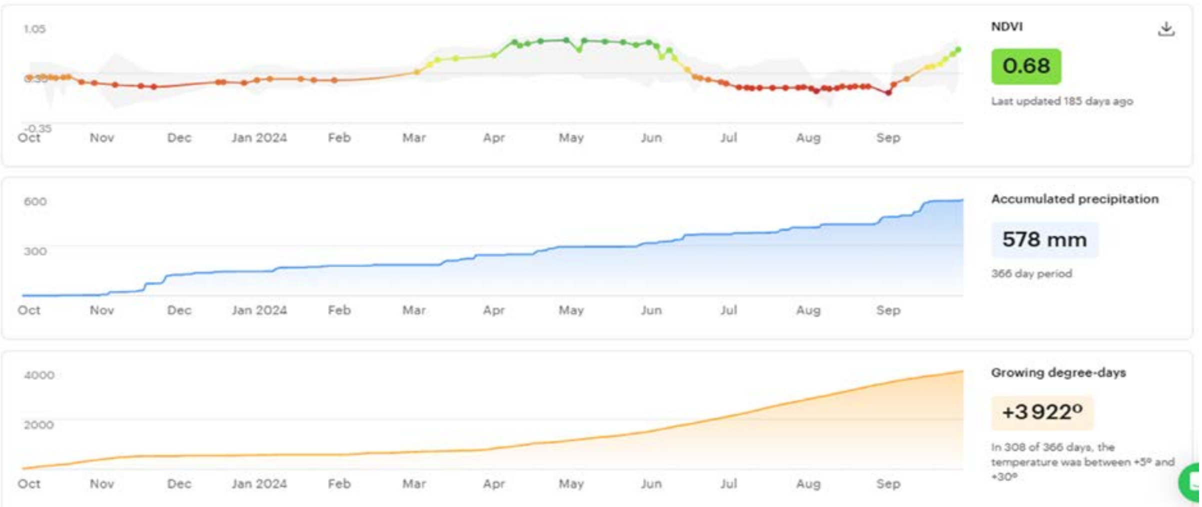

Fig. 7. Evolution of the NDVI index, precipitation, and growing degree days (GDD) in the 2023–2024 agricultural season.

4. Conclusions

The aim of the study was to assess the potential of GIS technologies applied in agriculture, with a focus on the use of the NDVI index and the OneSoil application to support differentiated input management decisions. Starting from the research question – Can NDVI and VRA support more efficient and sustainable agricultural management? – an analysis was carried out on a plot of land in Galați County, taking into account crop history, agroclimatic conditions, and available satellite data.

The results show that NDVI analysis allows for the clear identification of areas with reduced vigor, providing an objective basis for the differentiated application of fertilizers and sowing density. In the case analyzed, VRA simulations demonstrated savings of over 100 kg of nitrogen fertilizer and over 650 kg of seed without compromising yield, proving a real potential for increased efficiency in the use of inputs.

Compared to conventional practice, the OneSoil platform proved to be an accessible and intuitive tool, capable of providing farmers with a detailed and relevant picture of the internal variability of the plot. Thus, GIS data and NDVI analysis prove useful not only in diagnosis but also in supporting operational decisions in precision agriculture.

At the same time, the research also highlights certain limitations: NDVI's dependence on weather conditions, the lack of details about the causes of vegetation variation, and the need for field validation. The integration of VRA technology requires investment in compatible equipment and professional training, which may limit its adoption among small and medium-sized farmers.

The research hypothesis was confirmed: NDVI data, interpreted and integrated into a VRA approach, can support more efficient, better informed, and more sustainable agriculture. GIS platforms such as OneSoil are a starting point for farmers who want to adopt digital technologies in their decision-making process.

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