

From Agronomic Data to Digital Decision Support: Crop Monitoring Algorithms within the AGRARIAN Platform – The Romanian Pilot

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Abstract

Climate variability and increasing drought frequency represent major constraints for agricultural productivity in Romania, particularly for water-intensive crops such as maize. This study presents the development and implementation of crop monitoring algorithms within the AGRARIAN platform, focusing on the Romanian pilot. The system integrates agronomic data, including soil properties, crop development stages, and climatic variables, into a digital decision support tool for irrigation management. A climadiagram analysis for Grivița (Ialomița County) highlights seasonal imbalances between precipitation and evapotranspiration, leading to water deficits during critical growth stages. The methodology is based on the FAO-56 framework, incorporating soil water balance parameters such as field capacity (FC), wilting point (WP), total available water (TAW), and management allowable depletion (MAD). Crop evapotranspiration (ET_c) is estimated using stage-specific crop coefficients (K_c), while root depth dynamics determine the effective soil volume. The irrigation threshold is derived as a function of soil moisture, enabling real-time decision-making using sensor data. This study extends the classical FAO-56 approach by integrating real-time soil moisture data and nonlinear crop development modelling into a digital decision support framework. The results demonstrate the practical applicability of the AGRARIAN platform in improving irrigation efficiency and enhancing crop resilience under drought conditions.

Keywords: irrigation, decision support system, evapotranspiration, soil moisture, maize, digital agriculture.

1 Introduction

Agricultural systems in Romania are increasingly exposed to climate variability, characterized by rising temperatures, irregular precipitation patterns, and more frequent drought events. These changes significantly affect crop productivity, especially in southern regions such as Bărăgan, where water availability is a critical limiting factor. (CR. Păltineanu, 2007).

Maize (*Zea mays* L.), one of the dominant crops in Romania, is highly sensitive to water stress during key phenological stages. Ensuring optimal water supply is therefore essential for maintaining yield stability.

Recent research emphasizes the importance of integrating soil–plant–atmosphere interactions into irrigation management strategies. Evapotranspiration, soil moisture dynamics, and climatic variability must be considered together to accurately estimate crop water requirements. (Florentina Mincu, 2024)

Within this context, the AGRARIAN project aims to bridge the gap between agronomic knowledge and practical farm management by developing digital tools that support decision-making. The objective of this study is to present the crop monitoring algorithms implemented in the AGRARIAN platform for the Romanian pilot, with a focus on irrigation scheduling based on soil water balance.

2 Data and Method

The study integrates in-field meteorological measurements, soil hydrophysical parameters, and crop development modelling within a soil water balance framework to support irrigation decision-making.

The study was conducted in Grivița (Ialomița County), a representative agricultural area located in the southeastern part of Romania, characterized by frequent drought conditions and significant climatic water deficits. The selected site is part of the AGRARIAN project and represents one of the ten pilot farms where in-field monitoring infrastructure has been installed.

Meteorological data were collected using an automatic weather station installed directly in the field within the AGRARIAN platform. The dataset includes air temperature and precipitation recorded during the 2025 growing season. These in-situ measurements provide a high-resolution representation of local climatic conditions, enabling accurate assessment of crop water requirements.



Figure 1. AGRARIAN in-field weather station installed in the Grivița pilot farm, used for real-time monitoring of climatic and soil parameters.

2.1 Climatic analysis

A climadiagram was developed using the recorded temperature and precipitation data from the AGRARIAN weather station for the year 2025. This representation allows the identification of seasonal imbalances between water supply (precipitation) and atmospheric demand.

The analysis highlights periods during the growing season when precipitation is insufficient to meet crop water requirements, particularly during summer months, when evapotranspiration reaches its maximum. (Walter H.)

2.2 Crop development modeling using nonlinear thermal time (HTT)

Crop development was modeled using accumulated thermal time expressed as Growing Degree Days (GDD). However, instead of the classical linear approach, a nonlinear formulation based on heat thermal time (HTT) was implemented to better represent crop response to temperature.

The classical GDD approach assumes a linear increase in crop development with temperature above a base threshold. In contrast, the HTT method accounts for the nonlinear response of crop growth to temperature, considering three cardinal temperatures:

- T_{base} – minimum temperature for growth

- T_{opt} – optimal temperature
- T_{upper} – maximum temperature beyond which growth ceases

The hourly thermal contribution (HTT) is calculated using a beta function, which describes the increase and decline of growth rate with temperature. Daily thermal time (DTT) is then computed as the average of hourly values:

$$DTT = \frac{\sum HTT_i}{24}$$

The accumulated thermal time is expressed as:

$$GDD = \sum DTT$$

This nonlinear approach provides a more accurate representation of crop development under variable temperature conditions, especially during extreme heat events. The use of a nonlinear thermal time model represents an improvement over classical GDD approaches, allowing a more realistic simulation of crop development under fluctuating temperature conditions. (Guanglin Zhou, 2018)

2.3 Soil and crop parameters

Soil properties were defined based on texture classes, each associated with specific hydrophysical parameters:

- Field Capacity (FC) – maximum water retention after drainage
- Wilting Point (WP) – minimum water content available to plants

The difference between these values defines the total available water:

$$TAW = FC - WP$$

The effective water available to the crop also depends on root depth (Z_r), which varies dynamically with crop development stages.

Soil hydrophysical parameters were defined based on field-specific data provided by the National Research and Development Institute for Soil Science, Agrochemistry and Environment (ICPA Bucharest), with field capacity (FC) = 25% and wilting point (WP) = 10.5% for the studied soil.

Based on these values, the total available water (TAW) for the studied soil is 14.5%, representing the fraction of soil water that can be effectively used by the crop. This parameter plays a key role in determining irrigation thresholds within the soil water balance approach.

2.4 Crop water requirements

Crop evapotranspiration was estimated using the FAO-56 approach:

$$ET_c = K_c \cdot ET_o$$

where K_c varies according to crop stage and reflects plant development and canopy expansion. (Richard G. Allen, 2006)

2.5 Irrigation decision algorithm

The irrigation decision algorithm is based on the soil water balance approach and integrates soil, crop, and climatic data.

The Management Allowable Depletion (MAD) represents the fraction of total available water that can be depleted before crop water stress occurs. For maize, MAD was considered approximately 0.5, according to FAO-56. (Richard G. Allen, 2006)

The soil moisture threshold for irrigation was calculated as:

$$\theta_{\text{threshold}} = FC - MAD \cdot TAW$$

This threshold defines the minimum soil moisture level before irrigation is required.

The algorithm integrates:

- soil moisture sensor data
- precipitation
- evapotranspiration
- crop growth stage (via GDD)
- short-term weather forecast (7 days)

This allows real-time and predictive irrigation recommendations.

Irrigation is triggered when soil moisture falls below the threshold value, taking into account forecasted precipitation to avoid unnecessary water application.

3 Results

3.1 Climatic conditions in the study area

The climatic diagram developed for the Grivița location illustrates the monthly distribution of temperature and precipitation during the year 2025, based on data collected from the AGRARIAN in-field weather station. Although the analysed year can be considered relatively normal from a climatic perspective, the diagram reveals significant seasonal imbalances between water availability and atmospheric demand.

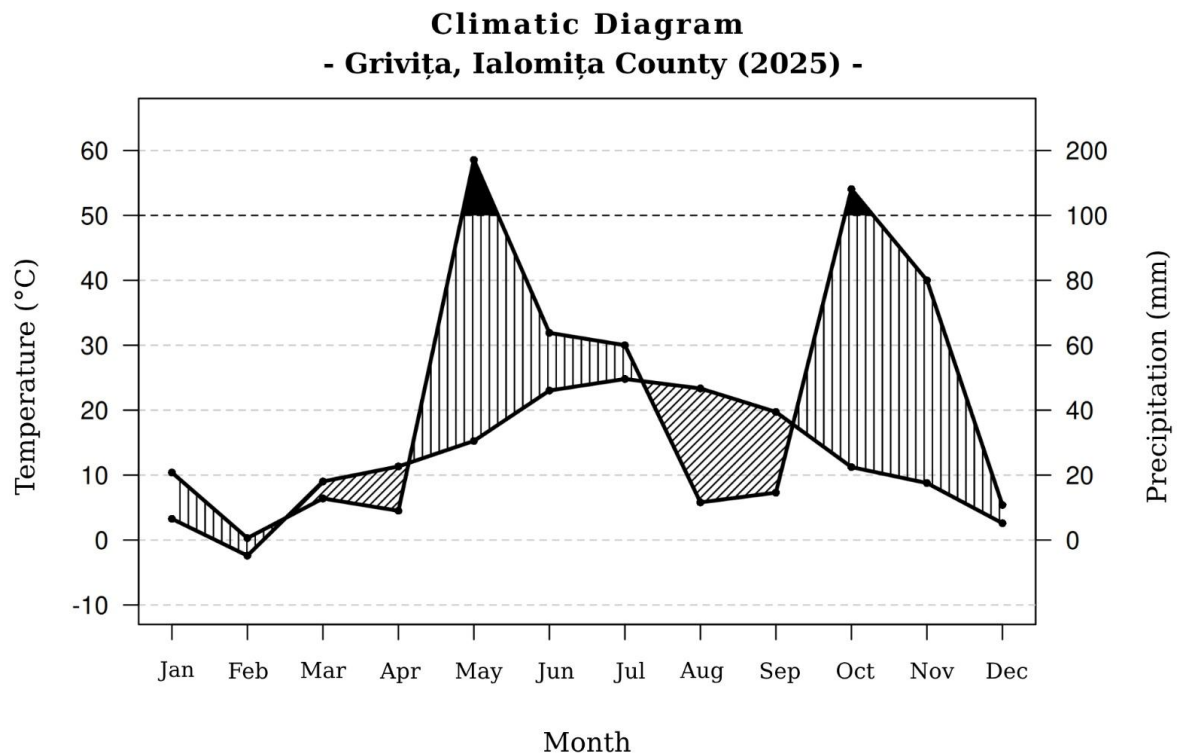


Figure 2 Climatic diagram based on meteorological data recorded in 2025 at the AGRARIAN weather station in Grivița, Ialomița.

▨ - Dry period

|||| - Wet period

■ - Precipitation >100 mm

A first critical period can be observed during early spring, particularly in March and April, which corresponds to the sowing period of maize. During this interval, precipitation levels remain relatively low, while temperatures begin to increase, leading to the onset of soil moisture deficits. This situation can negatively affect seed germination and early crop establishment, especially in soils with low water retention capacity.

A second and more pronounced deficit occurs during the summer months, particularly in July and August. These months coincide with the most critical phenological stages of maize, including tasseling, silking, fertilization, and grain filling. During this period, the climatic diagram indicates high temperatures combined with insufficient precipitation, resulting in a strong atmospheric water demand that is not compensated by rainfall.

This mismatch between crop water requirements and natural water supply leads to significant water stress, which is widely recognized as one of the main factors limiting maize productivity. Under such conditions, even in years considered climatically normal, the crop is exposed to periods of drought exactly during its most sensitive stages.

At the national level, these recurring seasonal deficits have contributed to a reduction in maize cultivated areas in recent years, as farmers face increasing uncertainty related to rainfall variability and yield stability. Consequently, irrigation becomes a critical factor in maintaining crop productivity.

The analysis highlights the necessity of implementing irrigation systems capable of compensating for these deficits, particularly during key growth stages. In this context, the AGRARIAN platform provides a practical solution by identifying critical periods of water stress and supporting timely irrigation decisions based on real-time data.

3.2 Regional drought context in Romania

To complement the local climatic analysis, a regional assessment of drought conditions was performed using data provided by the Administrația Națională de Meteorologie. The spatial distribution of precipitation anomalies in 2024 highlights the occurrence of moderate to extreme drought conditions across large agricultural regions of Romania.

The map indicates that southern and southeastern regions, including Ialomița County, experienced significant precipitation deficits. This confirms that the study area is representative of broader regional drought patterns, particularly in areas dominated by rainfed agriculture.

These climatic constraints are also reflected in agricultural statistics. According to Eurostat, Romania has traditionally cultivated large areas of maize, exceeding 2 million hectares in recent years. However, increasing drought frequency and variability in precipitation have significantly affected both crop yields and farmer decisions. (Grain maize and corn-cob-mix by area, production and humidity, 2025)

Recent agricultural reports indicate substantial yield reductions caused by prolonged drought and extreme temperatures, with maize production severely impacted in southern and eastern regions of the country. Under these conditions, the cultivated area has shown a declining trend, with 2025 marking a critical threshold in which maize areas dropped below 2 million hectares, reflecting the growing uncertainty associated with rainfed crop systems.

The integration of regional-scale drought assessment with local measurements from the AGRARIAN pilot provides a comprehensive understanding of water stress conditions affecting crop development. This multi-scale approach highlights not only the climatic pressure on agricultural systems but also its direct impact on land use and crop selection.

In this context, the implementation of digital irrigation decision support systems, such as the AGRARIAN platform, becomes increasingly relevant. By providing site-specific irrigation recommendations based on real-time data, these systems offer farmers practical tools to mitigate drought effects, stabilize yields, and maintain the economic viability of maize cultivation.

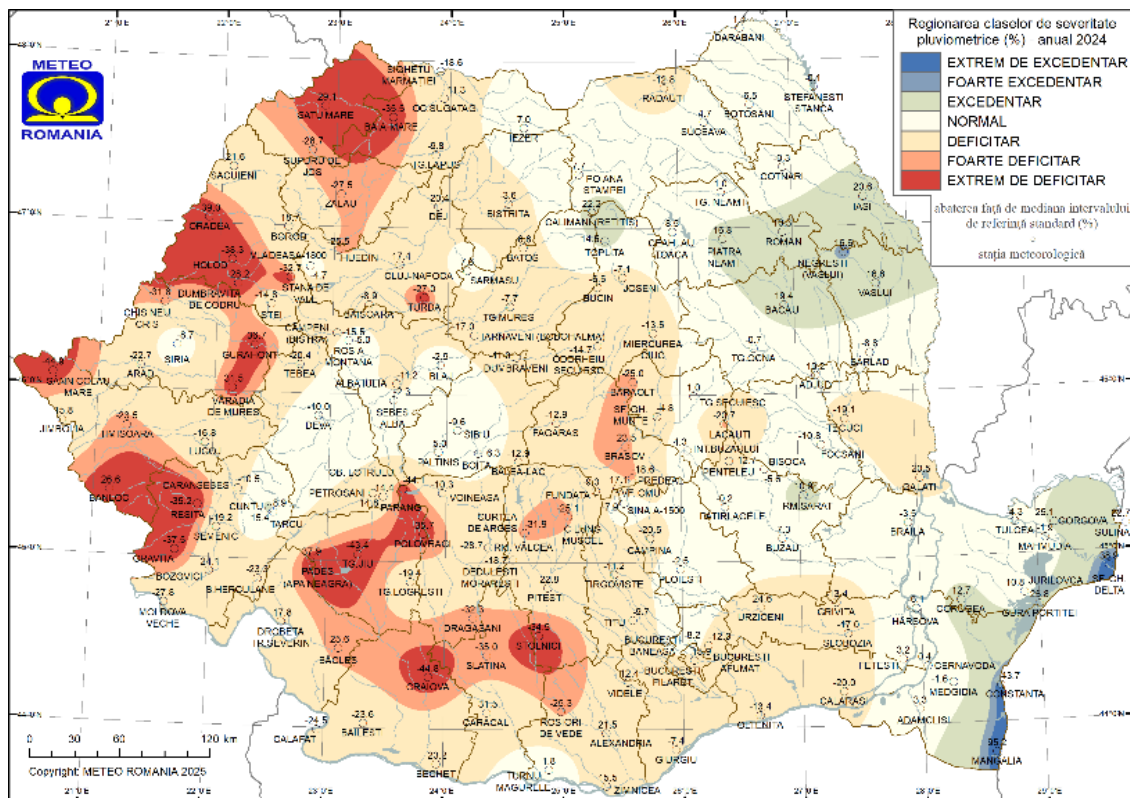


Figure 3. Regional distribution of precipitation anomalies in Romania (2024), highlighting drought severity classes (Source: National Meteorological Administration). Precipitation anomaly severity classes: extremely wet (dark blue), very wet (blue), wet (light green), normal (beige), dry (light orange), very dry (orange), extremely dry (red).

3.3 Soil and crop interaction

The soil–crop interaction is strongly influenced by the hydrophysical properties of the soil, which in the study area is classified as a vermic Chernozem, slightly leached, with loamy texture, belonging to the Chernisol class, according to data provided by the National Research and Development Institute for Soil Science, Agrochemistry and Environment (ICPA Bucharest). This soil type is characterized by a field capacity (FC) of 25% and a wilting point (WP) of 10.5%, indicating a relatively high-water storage capacity typical for loamy Chernozem soils.

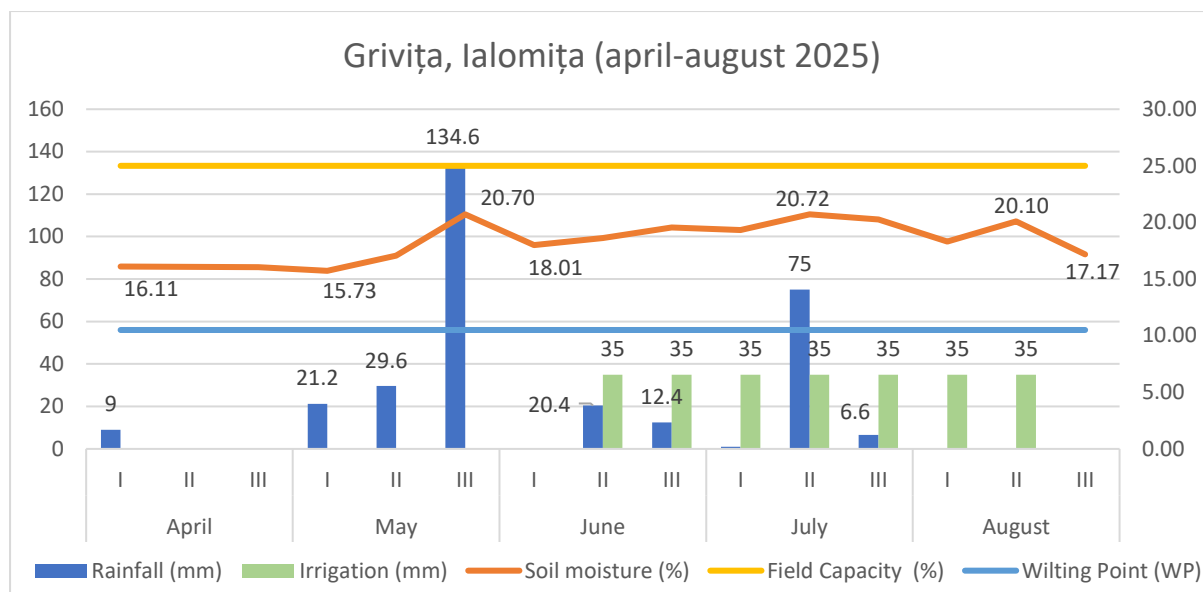


Figure 4. Soil Moisture Dynamics in Relation to Rainfall and Irrigation, Grivița, Ialomița (april-august 2025).

The temporal dynamics of soil moisture in relation to rainfall and irrigation for the maize crop are illustrated in Figure 4. The graph shows that soil moisture values fluctuate within the interval defined by FC and WP, reflecting the buffering capacity of this soil type.

During the early growth stages of maize (April–May), soil moisture remains relatively stable despite low precipitation, which can be attributed to the good water retention capacity of the Chernozem. A significant increase in soil moisture is observed following high rainfall events in May (e.g., 134.6 mm), bringing soil water content closer to field capacity and creating favorable conditions for early crop development.

As the crop progresses into critical phenological stages (June–August), including tasseling and grain filling, the soil moisture trend indicates increasing water depletion due to high evapotranspiration demand. Despite the inherent water-holding capacity of the loamy soil, natural precipitation becomes insufficient to sustain optimal moisture levels.

In this context, irrigation events (35 mm) are essential for maintaining soil moisture above the critical threshold and preventing water stress. Although soil moisture does not reach field capacity frequently during summer, it remains above the wilting point, ensuring that maize plants avoid severe stress but still experience moderate water limitations.

These results highlight the dual role of Chernozem soils: while they provide a favorable water reserve due to their texture, they are still vulnerable to depletion under prolonged dry conditions. The graph also confirms that irrigation scheduling aligned with soil moisture thresholds is necessary to optimize water availability and sustain crop productivity.

The reduction in soil moisture during June–August can be further explained by the occurrence of high maximum temperatures during the maize growing season, especially around flowering and grain filling. These stages are highly sensitive to combined heat and water stress, and the elevated thermal regime likely intensified evapotranspiration and crop water demand. As a result, the decline in soil moisture cannot be attributed solely to limited precipitation, but also to increased atmospheric demand during critical reproductive stages.

3.4 Algorithm performance

The irrigation algorithm successfully integrates agronomic and climatic data into a unified decision-making process. By transforming theoretical soil water balance concepts into measurable soil moisture thresholds, the system enables real-time irrigation alerts.

The inclusion of short-term forecast further enhances the system by anticipating future water deficits.

4 Discussion

The AGRARIAN platform demonstrates the effectiveness of integrating soil–plant–atmosphere processes into digital agriculture systems. The use of real-time data collected from in-field sensors represents a significant advancement compared to traditional approaches based on historical averages.

The incorporation of GDD ensures that crop development is dynamically modeled, while soil-specific parameters allow for localized irrigation decisions.

The results also emphasize the role of soil-specific properties in shaping the effectiveness of irrigation strategies. The vermic Chernozem with loamy texture identified in the study area provides a relatively high-water storage capacity ($FC = 25\%$, $WP = 10.5\%$), which contributes to buffering short-term water deficits. However, as shown by the soil moisture dynamics, this buffering capacity is insufficient to compensate for prolonged periods of high evapotranspiration during summer.

This highlights that even soils with favorable hydrophysical characteristics require well-timed irrigation to sustain optimal crop development. Therefore, the integration of soil-specific parameters into digital decision support systems is essential for improving the accuracy of irrigation recommendations and adapting management practices to local conditions.

5 Conclusion

This study presents a digital irrigation decision support system developed within the AGRARIAN project, which integrates agronomic knowledge with real-time monitoring data collected from in-field sensors. By combining climatic variables, soil properties, and crop development dynamics, the system provides a comprehensive framework for estimating crop water requirements and determining optimal irrigation timing.

The results obtained in the Romanian pilot highlight the importance of considering both local climatic variability and soil-specific characteristics in irrigation management. The analysis of the climatic diagram for Grivița confirms that water deficits occur even in years with relatively normal climatic conditions, particularly during critical stages of maize development. These findings emphasize the vulnerability of maize crops to water stress and the limitations of relying solely on natural precipitation.

Through the implementation of a soil water balance approach, combined with dynamic crop modeling based on thermal time, the AGRARIAN platform successfully translates complex agro-meteorological processes into actionable irrigation recommendations. This transformation from data to decision represents a key advancement in digital agriculture.

Overall, the Romanian pilot demonstrates that such systems can significantly improve water use efficiency, reduce the risk of yield losses, and enhance crop resilience under increasing drought pressure. The integration of real-time data and predictive capabilities further supports the transition towards more sustainable and adaptive agricultural practices.

The case study conducted in the Grivița pilot also demonstrates that even in soils with relatively high-water retention capacity, such as Chernozems, natural precipitation is insufficient to meet crop water requirements during critical growth stages. This underlines the necessity of integrating soil-specific parameters into irrigation scheduling tools to ensure efficient water use and enhance crop resilience under increasing drought pressure.

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