ASSESSMENT OF SOIL MOISTURE DEFICIT AND ADAPTATION OF IRRIGATION TECHNOLOGIES TO THE INCREASING FREQUENCY OF DROUGHTS

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Abstract

The increasing frequency and intensity of drought events in Romania, particularly in the regions of Dobrogea, Muntenia, and southern Moldavia, has led to a significant rise in soil moisture deficit and reduced water availability for agriculture. This study evaluates recent trends in soil moisture deficit and identifies appropriate irrigation technologies capable of maintaining crop productivity under enhanced water stress conditions. Multiannual climatic data (temperature, precipitation, and potential evapotranspiration) were analyzed to estimate crop water requirements and optimal irrigation intervals for major field crops using established methodologies, including the Penman–Monteith equation, FAO 56 guidelines, and the soil water balance method. Results show a 10–20% increase in potential evapotranspiration and reduced precipitation during key growth stages, leading to seasonal deficits of 100–250 mm. Maize and sunflower were the most affected, with yield reductions of 30–60% in the absence of irrigation. Drip irrigation proved the most efficient technology, enabling water savings of up to 35–40% compared with sprinkler irrigation while maintaining optimal root-zone moisture. The study emphasizes the need for precision irrigation, soil moisture monitoring systems, and regulated deficit irrigation to improve water use efficiency. Adapting irrigation strategies and modernizing infrastructure are essential to enhancing the resilience of agroecosystems under increasingly severe drought conditions.

Key words**: **moisture deficit drought, irrigation regime, evapotranspiration, precision irrigation

INTRODUCTION

In recent decades, climate change has led to a significant increase in the frequency and intensity of drought events worldwide, strongly affecting soil water regimes and agricultural productivity. At the global scale, drought and desertification affect approximately 47% of arid lands, expressed through different degrees of aridity and land degradation (Huma, 2004). This phenomenon is accompanied by a continuous reduction in available water resources for irrigation, with major implications for food security and sustainable agriculture.

Climate variability influences all economic sectors; however, agriculture remains the most vulnerable, as its dependence on water availability makes it highly sensitive to hydrothermal fluctuations (Chitu et al., 2015). In Romania, climate change effects are already evident and are expected to intensify through rising air temperatures, altered precipitation patterns, accelerated snow and ice melting, and sea level rise. These changes generate differentiated impacts on ecosystems, economic

sectors, population health, and regional vulnerability levels (Daniel et al., 2019).

Romania is particularly exposed to drought risk in Dobrogea, Muntenia, and southern Moldavia, regions characterized by increasing aridity trends. The significant spatial and temporal irregularity of rainfall, combined with rising annual mean temperatures and increasing potential evapotranspiration, has led to the intensification of soil moisture deficit and the frequent occurrence of pedological drought. At present, soil moisture deficit represents the main limiting factor for crop production, negatively affecting plant physiological processes, nutrient uptake efficiency, and yield stability.

Under these conditions, ensuring an optimal soil water balance has become a major challenge for modern agriculture. As crop water requirements increase while water resources become increasingly limited, irrigation is no longer a supplementary practice but a strategic component of climate resilience. Conventional irrigation systems are often inadequate under current climatic conditions, making the transition toward modern, high-efficiency irrigation technologies mandatory. Drip irrigation, precision irrigation, soil moisture sensors, and digital monitoring technologies represent key adaptation pathways to increasing water stress.

The impact of water stress induced by different sowing dates and irrigation regimes is still not fully understood. In the absence of additional limiting factors such as weeds, diseases, or nutrient deficiencies, yield reduction due to water shortage strongly depends on the phenological stage of the crop. Previous studies indicate that soybean, for example, exhibits variable sensitivity to water stress at different developmental stages, including the vegetative phase, flowering, pod formation, and seed filling (Brevedan & Egli, 2003).

In this context, the present study aims to analyze the dynamics of soil moisture deficit under intensifying drought conditions, to assess its impact on crop water consumption, and to identify the most efficient modern irrigation technologies capable of ensuring sustainable crop production under climate change. The findings provide a scientific basis for improved irrigation management strategies and for enhancing the resilience of agroecosystems exposed to increasing drought risk.

MATERIALS AND METHODS

The study was based on the analysis of multiannual climatic data regarding air temperature, precipitation, and potential evapotranspiration, collected from representative meteorological stations located in southeastern Romania, within areas characterized by a high risk of drought (Dobrogea, Muntenia, and southern Moldavia).

The analyzed period included several consecutive years, relevant for highlighting recent trends in drought intensification.

Crop water requirements for the main economically important crops (wheat, maize, sunflower, and soybean) were determined based on crop evapotranspiration (ETc), calculated using the Penman -Monteith method in accordance with the FAO 56 methodology, applying specific crop coefficients for each crop and growth stage. In parallel, the soil water balance method was used to establish optimal irrigation scheduling and irrigation intervals, depending on the dynamics of available water within the active soil layer.

Soil moisture deficit was determined by comparing mean precipitation values with crop water requirements, at different probability levels corresponding to the climatic variability of the analyzed regions. Pedological drought was assessed by correlating climatic data with soil water reserves, expressed along the

characteristic soil profile of each meteorological station.

The performance of irrigation technologies was evaluated through a comparative analysis of the main systems used under frequent drought conditions sprinkler irrigation and drip irrigation based on both field experimental data and information from the scientific literature. The analyzed parameters included irrigation norm, irrigation frequency, water losses through evaporation and deep percolation, and distribution uniformity.

Water use efficiency (WUE) was calculated as the ratio between crop yield and the total volume of water consumed, expressing the performance of each irrigation technology under water stress conditions. Statistical analysis of the results was applied to identify significant differences among the studied technological variants.

RESULTS AND DISCUSSIONS

The analysis of multiannual climatic data revealed a clear intensification of drought conditions in southeastern Romania. In recent years, potential evapotranspiration values have increased by approximately 10–20%, while precipitation amounts recorded during the critical growth periods of crops have shown a decreasing trend. This hydrothermal imbalance has significantly amplified the soil moisture deficit and increased the frequency of pedological drought(Table1).

The studied areas frequently recorded seasonal water deficits ranging between 100 and 250 mm during the growing season. As a result, irrigation requirements exceeded classical recommendations by 15–30%, depending on the crop and the climatic year. These deficits strongly affected crop development, especially under rainfed conditions, when soil water reserves were insufficient to sustain optimal growth.

Table1. Evolution of potential evapotranspiration, precipitation, and water deficit in southeastern Romania

Year	Potential evapotranspiration (mm)	Precipitation (mm)	Water deficit (mm)
2015	720	610	110
2016	740	585	155
2017	765	560	205
2018	790	540	250
2019	820	550	270
2020	860	520	340
2021	880	530	350
2022	905	510	395
2023	935	500	435

Among the analyzed crops, maize and sunflower proved to be the most sensitive to water stress. In the absence of irrigation, yield reductions ranged between 30 and 60% during drought years, confirming the high vulnerability of these crops to soil moisture deficit. Wheat and soybean showed relatively better tolerance; however, significant yield losses were also recorded for these crops, especially during the flowering and grain (or seed) filling stages (Table2)

Table 2.Yield reduction of major crops under drought conditions

Crop	Yield reduction without irrigation (%)
Maize	30–60 (≈55)
Sunflower	30–60 (≈50)
Wheat	≈20–30 (≈25)
Soybean	≈30–40 (≈35)

The comparative evaluation of irrigation technologies highlighted a clear advantage of drip irrigation over sprinkler irrigation. Drip irrigation significantly reduced water losses through evaporation and wind drift and ensured a much more uniform moisture distribution within the active root zone. As a result, water savings of up to 35–40% were achieved compared with sprinkler irrigation, while

optimal moisture conditions for crop development were maintained.

Table 3. Comparative performance of sprinkler and drip irrigation technologies under drought conditions

Irrigation technology	Water losses	Moisture distribution	Water savings (%)	Overall performance
Sprinkler Irrigation	High (evaporation and wind drift)	Moderate uniformity	0 (baseline)	Medium
Drip Irrigation	Low	High uniformity in root zone	35–40	High

Water use efficiency (WUE) values were consistently higher under drip irrigation for all analyzed crops, indicating a superior conversion of water into biomass and yield. The largest improvements in water use effciency were recorded for maize and soybean,highlighting the strong potential of localized irrigation systems to enhance productivity under conditions of limited water availability.
The adaptation of irrigation technologies to current drought conditions does not only involve the replacement of conventional systems, but also the implementation of advanced water management strategies. Regulated deficit irrigation, the use of soil moisture sensors, and remote monitoring tools allow precise irrigation scheduling based on actual crop water requirements. Moreover, the application of split irrigation norms adapted to critical phenological stages proved to be an efficient strategy for optimizing water consumption without significantly affecting yield (Figure 1).

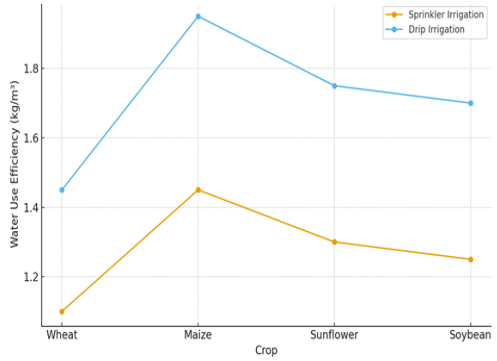

Figure 1.Comparison of water use efficiency by irrigation technology

The modernization of irrigation infrastructure represents another essential component of adaptation to climate change. Reducing water losses through pipeline rehabilitation, network automation, and pressure regulation significantly contributes to improving the overall efficiency of water use at both farm and irrigation system levels.
The obtained results are consistent with recent studies in the scientific literature, which emphasize the urgent need for a transition toward precision irrigation systems in the context of climate change. The increasing pressure on water resources, correlated with the growing variability of climatic factors, requires the adoption of integrated and flexible water management strategies capable of ensuring sustainable agricultural production.

CONCLUSIONS

The analysis of multiannual climatic data clearly indicates an intensification of drought conditions in southeastern Romania, driven by increasing potential evapotranspiration and decreasing precipitation during critical crop growth periods. Seasonal water deficits, frequently ranging between 100 and 250 mm, significantly affect crop water consumption and impose the need for

reassessing irrigation regimes under current climate change conditions. Among the analyzed crops, maize and sunflower proved to be the most sensitive to water stress, showing major yield reductions under rainfed conditions, while wheat and soybean exhibited relatively higher tolerance, although with considerable losses during critical phenological stages. Drip irrigation showed a clear advantage over sprinkler irrigation, ensuring water savings of up to 35–40% and a more uniform moisture distribution within the active root zone. Water use efficiency was consistently higher under drip irrigation, particularly for maize and soybean, confirming the high potential of localized irrigation systems under limited water availability. The adaptation of irrigation technologies requires not only the modernization of infrastructure but also the implementation of advanced water management strategies, such as regulated deficit irrigation, soil moisture monitoring, and remote sensing-based irrigation scheduling. Under increasing pressure on water resources and growing climatic variability, the adoption of integrated and flexible irrigation management strategies is essential for ensuring sustainable agricultural production and enhancing the resilience of agroecosystems.

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