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WATER USE EFFICIENCY IN IRRIGATED AGRICULTURE IN ROMANIA: OPTIMIZATION STRATEGIES IN THE CONTEXT OF CLIMATE CHANGE

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Abstract

Climate change significantly impacts agriculture, especially in Romania's semi-arid and sub-humid regions, such as Dobrogea, Southern Moldova, and Muntenia. This study analyzes water use efficiency in irrigated agriculture, considering the increase in average annual temperatures and its effect on water consumption. The three irrigation methods – drip, sprinkler, and furrow irrigation – were compared to identify the most efficient strategies. The results indicate that drip irrigation is the most efficient, with minimal water losses and optimized consumption, although high initial costs may pose a disadvantage. Sprinkler irrigation demonstrates moderate efficiency but is influenced by weather conditions, while furrow irrigation has high water losses and low efficiency. In scenarios where temperatures increase by 2°C and 5°C, water consumption for major crops – maize, sunflower, soybean, and sugar beet – increases by up to 25%. The study emphasizes the need to modernize irrigation infrastructure and adopt sustainable technologies to address climate challenges. Financial support for implementing drip irrigation and educational programs for farmers is strongly recommended.

Key words: *adaptation, climate change, evapotranspiration modeling, irrigation efficiency.*

INTRODUCTION

This study aims to test the hypothesis that climate-induced evapotranspiration changes significantly affect irrigation efficiency in southeastern Romania, and that drip irrigation provides superior water use efficiency under these conditions.

Globally, drought and desertification affect approximately 47% of arid lands, manifesting in varying degrees of aridity. In recent years, drought-affected areas have progressively expanded across most regions of Romania, accompanied by a decline in water resources available for irrigation (Humă, 2004). Climate variability impacts all sectors of the economy, but agriculture remains the most vulnerable, with its effects becoming increasingly severe as climate change intensifies (Chitu et al., 2015). In Romania, the effects of climate change are already evident and are expected to manifest through rising temperatures, altered rainfall patterns, melting ice and snow, and rising sea levels. The impact on ecosystems, economic sectors, public health, and regional vulnerability varies across the country (Daniel et al., 2019).

Without appropriate mitigation and adaptation measures, climate change is projected to significantly reduce agricultural productivity. Plant breeders play a crucial role in developing varieties and hybrids with low evapotranspiration requirements, thereby supporting agricultural adaptation to changing climatic conditions (IPCC Press Release, 2018).

Increasing temperatures and intensifying aridification are expected to lead to higher evapotranspiration rates and greater water deficits, severely impacting crop yields. Adapting to these conditions requires the development of efficient water management strategies and the implementation of optimized irrigation systems. Adapting to these climatic conditions requires the development of efficient water management strategies and the use of optimized irrigation systems. A crucial role belongs to breeders, who must create drought-resistant genotypes capable of maintaining productivity under water stress conditions (Niţu et al., 2023). Choosing an appropriate irrigation scheduling strategy is essential to optimize plant physiological processes, thus enhancing crop yields (Kumar Jha et al., 2018). Moreover, a well-designed irrigation plan significantly reduces water and energy use. Conversely, improper irrigation practices-such as excessive or insufficient water application-generally result in lower grain yields, reduced irrigation water productivity, and environmental problems including land flooding, soil salinization, and rising groundwater levels (Yohannes et al., 2019; Almeida et al., 2022; Quiloango-Chimarro et al., 2022). The impact of climate change on the yields of major agricultural crops worldwide is expected to be negative (Roudier et al., 2011), while the exact effect remains highly uncertain when high temperatures, increased atmospheric CO2 concentrations, and changes in precipitation patterns occur simultaneously (Roudier et al., 2011). In Romania, the effects of climate change are being felt through rising temperatures, altered precipitation patterns, melting glaciers and snow, and rising sea levels. Extreme weather events, which cause negative environmental impacts (floods and droughts), are expected to become more frequent and intense in many regions (Rummukainen, 2012).The effects of water stress resulting from various sowing dates and irrigation rates is not yet fully understood. In the absence of weeds, diseases, nutritional deficiencies, or other limiting factors, the reduction in yield caused by water shortage depends on the phenological stage of the plant. Research has shown that soybeans exhibit varying sensitivity to water stress at different developmental stages, such as the vegetative phase, flowering, pod formation, and seed filling (Brevedan & Egli, 2003). Studies suggest that supplementary or deficit irrigation applied during specific periods of the growing season can significantly improve water use efficiency and positively influence soybean yield (Giménez et al., 2017; Jha et al., 2018). Drip irrigation, an advanced and water-efficient method, ensures the maintenance of plant roots in optimal moisture conditions for extended periods, thus promoting both physiological activity and crop development (Yan et al., 2022).

MATERIALS AND METHODS

The study was conducted using climatic data from five meteorological stations located in southeastern Romania: Constanța, Tulcea, Galați, Brăila, and Călărași. These regions are representative for irrigated agriculture and are frequently exposed to water stress caused by increased temperatures and rainfall variability.

The selected crops - corn, soybean, and wheat - are among the most important in Romanian agriculture, each with specific sensitivities to water deficits. The decision to evaluate these crops was based on their widespread cultivation and different growing periods and evapotranspiration demands.

Climatic data, including, the annual average temperature and precipitation data used in the study were obtained from the Romanian National Meteorological Administration (ANM), corresponding to the year 2024. To calculate the reference evapotranspiration (ET_0), the Penman-Monteith FAO-56 equation was used, which incorporates air temperature, solar radiation, wind speed (3.2 m/s), and relative humidity (65%). A constant average net radiation of 15.5 MJ/m²/day was used for the southeastern region.

The specific crop evapotranspiration (ETc) was calculated by applying crop coefficients (Kc) for each growth stage-initial, development, and maturity-following FAO guidelines. The crop growth stages were defined as follows:

- Corn: 30–50–40 days
- Soybean: 25–55–35 days
- Wheat: 30–60–45 days

The calculations were carried out using Microsoft Excel and Python to ensure accuracy in the estimation of evapotranspiration and for the structured presentation of results.

Soil conditions were considered in three standard texture scenarios-sandy, loamy, and clayey-because soil water retention capacity significantly affects irrigation efficiency.

In 2024, southeastern Romania was severely affected by extreme climate events, with high temperatures and heavy rainfall during certain periods. The summer was dominated by an exceptionally intense and prolonged heatwave, considered the most severe in the country's recent history. Between May 31 and July 31, heatwave conditions persisted for 46 out of 62 days, accounting for 75% of this period. The average summer temperature was 0.69°C higher than the 1991-2020 reference period, surpassing the previous record set in 2023. At the end of summer, on august 30 and 31, a quasi-stationary extratropical cyclone over the Black Sea brought heavy rainfall, causing floods in several coastal towns. In just 24 hours, precipitation exceeded 100 mm in numerous areas, with maximum recorded values of 225.9 mm in Mangalia, 145 mm in Agigea, and 118 mm in Tuzla (Tabel 1).

Table 1. Climatic data for Southeastern Romania - 2024

Weather station	Annual average temperature (°C)	Annual precipitation (mm)
Constanța	14.8	450
Tulcea	14.5	420
Galați	14.2	480
Brăila	14.3	460
Călărași	14.6	440

To calculate the total evapotranspiration (ETc) for corn, soybean, and wheat at each weather station in southeastern Romania, the Penman-Monteith FAO 56 equation was used to determine the reference evapotranspiration (ET_0), and then the values were adjusted for each crop using crop coefficients (Kc).

$$ETo = \frac{0{,}408\ x\,\Delta\, x(Rn-G)+\gamma\, x\frac{900}{T+273}\, x\, u\, 2(es-ea)}{\Delta+J\ \ x(\ 1+0{,}34\ x\, u\ 2)} \quad (1)$$

where:

- ET_0 - reference evapotranspiration (mm/day);
- R_n - net radiation at the crop surface (MJ/m²/day) - the average value used for southeastern Romania: 15.5 MJ/m²/day;
- G - soil heat flux - considered 0 for long periods;
- T - average air temperature (°C), obtained for each weather station;
- u_2 - wind speed at 2 m (m/s) – the average value used for southeastern Romania: 3.2 m/s;
- e_s - saturation vapor pressure (kPa);
- e_a - actual vapor pressure (kPa);
- Δ - slope of the vapor pressure curve (kPa/°C);
- γ - psychrometric coefficient (kPa/°C).

These values were calculated for each weather station (Constanța, Tulcea, Galați, Brăila, Călărași) using the annual average temperature specific to each location.
After calculating ET_0 for each weather station, crop coefficients (Kc) were applied to obtain the specific evapotranspiration for each crop.

$$ETe = ETo\ x\ Kc \quad (2)$$

where:

- ETe - specific evapotranspiration for each crop;
- ETo - reference evapotranspiration (mm/day);
- Kc - crop coefficients.

For each crop, the Kc coefficients vary depending on the growth stage (Tabel 2).

Table 2. Coefficients vary depending on the growth stage (Kc)

Crop	Initial stage	Development stage	Maturity stage
Corn	0.3	1.2	0.6
Soybean	0.4	1.15	0.5
Wheat	0.4	1.1	0.5

The duration of each phase (in days) is presented in Table 3.

Table 3. The duration of each phase, in days

Crop	Initial stage (days)	Development stage (days)	Maturity stage (days)
Corn	30	50	40
Soybean	25	55	35
Wheat	30	60	45

For each crop and weather station, the total evapotranspiration was calculated as follows:

$$ETc\ total = (ET_0 \times Kc_0 \times \text{number of days}) + (ET_0 \times Kc_1 \times \text{number of days}) + (ET_0 \times Kc_2 \times \text{number of days}) \quad (3)$$

The formula (3) was applied for corn, soybean, and wheat at each of the five weather stations.

RESULTS AND DISCUSSIONS

The total evapotranspiration for each crop was calculated for each station, with the highest values observed in Constanța and Călărași. For example, wheat reached a seasonal ETc of 437.03 mm in Constanța and 434.09 mm in Călărași, followed by corn and soybean.

In Galați and Brăila, where temperatures were slightly lower and precipitation somewhat higher, ETc values were reduced by up to 10%, suggesting a lower irrigation requirement. This confirms that regional climatic differences significantly affect irrigation planning.

Among irrigation methods, drip irrigation - due to its localized application and minimal evaporative losses - proved to be the most efficient system for meeting crop water demands. Sprinkler irrigation performed well in loamy soils, while furrow (surface) irrigation showed the lowest efficiency, particularly in sandy soils.

Figure 1 illustrates the variation in total crop evapotranspiration (ETc) across the five weather stations for corn, soybean, and wheat.

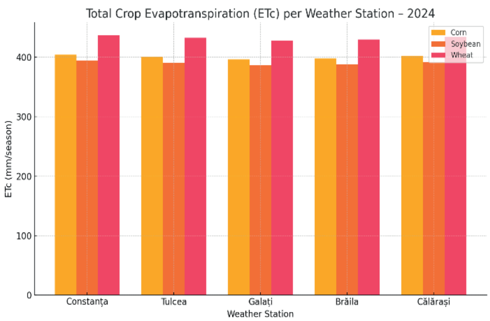

Figure 1. Seasonal crop evapotranspiration (ETc) by weather station - 2024

The graphical comparison highlights the higher ETc values observed for wheat across all stations, especially in Constanța and Călărași, and confirms the lower water requirements of soybean. This visual representation supports the numerical findings and emphasizes the impact of regional climatic differences on crop water needs.

Climate projections indicate that an increase of 2°C in average temperature could lead to a 6-10% increase in evapotranspiration, while a 5°C rise may result in a 15-20% increase, especially in already water-stressed regions such as Dobrogea. These estimations highlight the urgency of adapting irrigation strategies to cope with climate variability.

The results are consistent with previous studies (Chitu et al., 2015), confirming that crop water requirements in southern and southeastern Romania are increasing in response to climate trends. This underscores the need for investment in modern irrigation systems and support programs for farmers.

After performing all calculations, the total seasonal evapotranspiration was obtained for each crop and each weather station. These values represent the total amount of water required to ensure optimal plant growth under irrigation conditions (Tabel 4).

Tabel 4. Total seasonal evapotranspiration for each crop and each weather station

Weather station	Crop	Total Evapotranspiration (mm/season)
Constanța	Corn	404.41
Constanța	Soybean	394.63
Constanța	Wheat	437.03
Tulcea	Corn	400.34
Tulcea	Soybean	390.66
Tulcea	Wheat	432.63
Galați	Corn	396.28
Galați	Soybean	386.69
Galați	Wheat	428.24
Brăila	Corn	397.63
Brăila	Soybean	388.01
Brăila	Wheat	429.7
Călărași	Corn	401.7
Călărași	Soybean	391.98
Călărași	Wheat	434.09

The total evapotranspiration varies slightly between weather stations, being influenced by the annual average temperature and the specific precipitation levels of each area.

Călărași and Constanța record higher evapotranspiration values for all crops, indicating a greater need for irrigation, probably due to higher temperatures and lower precipitation compared to other stations. Galați and Brăila show lower total evapotranspiration values, suggesting a reduced water demand for crops, possibly due to higher precipitation levels or slightly lower temperatures.

Wheat requires the highest amount of water for the growing season across all weather stations (values ranging from 428.24 mm in Galați to 437.03 mm in Constanța). This is explained by its longer vegetative cycle and constant moisture requirements, especially during the stem elongation and grain filling stages.

Corn has a moderate water requirement, ranging from 396.28 mm in Galați to 404.41 mm in Constanța, which confirms the high water demands of this crop during the vegetative growth and flowering stages.

Soybean requires the least amount of water, with values ranging from 386.69 mm in Galați to 394.63 mm in Constanța, as it is a drought-adapted crop with a root system that efficiently absorbs water from the soil.

Constanța and Călărași counties have the highest total evapotranspiration values for all analyzed crops. This is due to higher temperatures and lower precipitation levels, which increase the risk of water stress. Under these conditions, implementing efficient irrigation systems is essential to maintain high agricultural yields.

Solutions for optimizing irrigation in Constanța and Călărași:

- Drip irrigation - ensures efficient water use by applying precise amounts directly to the plant roots, reducing evaporation losses.
- Sprinkler irrigation - an effective method for uniform water distribution, especially in areas with well-drained soils.
- Controlled deficit irrigation - adjusting the volume and frequency of irrigation according to the crop development stage and water availability.

In these regions, it is also essential to apply soil water conservation techniques, such as mulching, minimum tillage, and crop rotation, to reduce evapotranspiration and optimize water use.

Galați and Brăila counties have lower total evapotranspiration values, indicating a reduced need for irrigation compared to Constanța and Călărași. This may be due to more frequent precipitation or slightly lower average temperatures.

Optimizing water use in Galați and Brăila:

- Supplemental irrigation - can be applied only during critical periods, such as flowering and grain formation in wheat, soybean, or corn.
- Soil moisture monitoring - using moisture sensors to adjust irrigation frequency and volume based on the actual water needs of plants.
- Rainwater harvesting and storage – implementing rainwater collection systems to reduce dependency on irrigation.

These measures can help reduce water consumption and increase the efficiency of available resource utilization.

CONCLUSIONS

Climate change, characterized by rising temperatures and altered precipitation patterns, directly affects water use efficiency in agriculture, especially in the southeastern regions of Romania. The results obtained show that total evapotranspiration varies depending on geographic location, crop type, and local climatic conditions, with the highest values recorded in Constanța and Călărași counties.

Among the analyzed irrigation methods, drip irrigation proved to be the most efficient in terms of water consumption, offering minimal losses and precise control over applied volumes. Sprinkler irrigation is a viable alternative in areas with well-drained soils, while furrow irrigation is less efficient due to significant water losses.

To address current and future climate challenges, it is essential to modernize irrigation infrastructure, implement soil water conservation practices, and adapt irrigation strategies to the specific conditions of each region.

Financial support for the implementation of modern technologies, along with training programs for farmers, is recommended to improve water use efficiency and ensure the sustainability of agricultural production.

Promoting drip irrigation in regions affected by water scarcity or high temperatures is essential for efficient resource management. It is necessary to subsidize efficient irrigation systems to support farmers in transitioning to modern methods. Irrigation technologies must be adapted according to soil type, with particular attention to avoiding furrow irrigation in sandy soils. Additionally, investments in agricultural research are needed to evaluate the performance of different irrigation methods under various climatic conditions. Last but not least, farmer education and training on best water management practices represent a key pillar for the success of these measures.

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