EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology, 2025, 26(4), 50–58
https://doi.org/10.12912/27197050/200563
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Received: 2025.01.08
Accepted: 2025.02.15
Published: 2025.03.01

Irrigation water needs analysis and management strategies in the Tadla irrigation zone: A case study of sugar beet plots

Houda Nassah[1,2*], A. Zitouni[2], O. Tibssirte[2], Lamia Daghor[2], Hicham Chattoui[3], Laila Midhat[4]

[1] Geosciences Semlalia Laboratory, Faculty of Sciences Semlalia, University cadi Ayyad Marrakech, Morocco
[2] Department of Health and Agro-Industry Engineering, High School of Engineering and Innovation of Marrakesh, Private University of Marrakesh, Road Amezmiz, Marrakech, Morocco
[3] Higher Institute of Nursing and Health Techniques in Marrakech, Ministry of Health, Morocco
[4] National Center of Study and Research on Water and Energy, Laboratory of Hydrobiology, Ecotoxicology and Sanitation, Faculty of Sciences Semlalia, University cadi Ayyad Marrakech, Morocco
* Corresponding author's e-mail: houda.nassah@gmail.com

ABSTRACT

This study aims to evaluate irrigation water needs and propose effective management strategies for sugar beet cultivation in the Tadla irrigation perimeter, a semi-arid region facing increasing water scarcity despite its significant agricultural potential. Using the Blaney-Criddle formula, water needs were calculated by determining evapotranspiration (ETo) for three sowing periods: early, seasonal, and late. Data were collected from sugar beet growers using both drip and gravity irrigation systems, allowing for a comparison between actual water use and calculated crop water requirements. The results revealed that 46% of sugar beet farmers over-irrigate, leading to considerable water wastage, while 54% suffer from irrigation deficits due to the region's water scarcity. Net water requirements were estimated at 4204.8 m³/ha for early sowings, 4575.01 m³/ha for seasonal sowings, and 5529.58 m³/ha for late sowings, over the entire growing cycle. The study also found that all sugar beet growers using gravity irrigation systems exceed crop water needs, resulting in significant inefficiencies and water loss. Conversely, drip irrigation was shown to be a more efficient irrigation method, provided that irrigation practices align with crop-specific needs. However, the study is limited to sugar beet cultivation within the Tadla region, and the findings may not directly apply to other crops or regions. Further research could expand the study to include additional crops and assess the long-term impacts of implementing water-saving practices. The practical value of this research lies in its potential to improve irrigation efficiency and reduce water waste, offering actionable insights for farmers and policymakers. This study bridges the gap between theoretical water optimization and practical implementation in semi-arid regions, contributing to more sustainable water management practices and ensuring the future viability of agriculture in arid environments.

Keywords: irrigation water optimization, water net requirement, sugar beet, arid climate, water scarcity.

INTRODUCTION

Water scarcity is a major problem in Mediterranean regions, especially in Morocco (Hamdy and Lacirigniola, 2005), and particularly in arid areas where farming relies heavily on irrigation (Al Hamedi et al., 2024). The growing demand for food, driven by population growth, puts significant pressure on water resources, making efficient irrigation water use essential to sustain agriculture in these regions (Benoit and Comeau, 2006; Kobry and Eliamani, 2004). Agriculture, which uses a large share of water in Morocco (Chehbouni et al., 2008), is especially vulnerable to the current water crisis. This highlights the need for sustainable management strategies tailored to the challenges of arid and semi-arid areas (Kahil et al., 2015).

To address these challenges, Morocco launched the Green Morocco Plan (PMV) in

2008. This is a comprehensive strategy to improve agricultural performance while tackling the critical issue of water scarcity. One key part of this plan is to optimize irrigation water use by promoting localized irrigation systems, such as drip irrigation, which aim to increase water efficiency and reduce losses (PMV, 2008). Estimates suggest this transition could save up to 1.4 billion cubic meters of water annually, helping to ensure sustainable agricultural development in the face of growing climate and resource challenges (Bouazzama et al., 2015).

However, despite the ambitious goals and progress of the Green Morocco Plan, water scarcity remains a persistent challenge. The World Water Vision report highlights that the global water crisis is not only caused by limited availability but also by poor management practices, which have significant impacts on people and the environment (Saraiva et al., 2020). This issue is particularly relevant in Morocco, where solutions from the Green Morocco Plan, though promising, appear increasingly insufficient to meet the rising demand for efficient water use.

Several studies have revealed significant gaps in the practical application of localized irrigation systems, often considered a benchmark for water management (Nassah et al., 2018, 2020). The 2022 agricultural report by Jesko Hentschel emphasized that the measures under the Green Morocco Plan must be supported by more efficient and rational water-use practices. This includes addressing persistent inefficiencies in current irrigation systems and promoting adaptive management that considers crop needs, soil conditions, and climate variability (Khalid and Moujahid, 2020; MAPM, 2020). It underlines the urgency for targeted research to close the gap between the theoretical potential of localized systems and their real-world application. This ensures these systems meet their goal of sustainable water resource management.

In this context, the aim of this study is to fill this gap by evaluating irrigation practices in the irrigated area of Tadla. Specifically, it compares the water supplied to sugar beet crops with the calculated net water needs during different growth stages, analyzing the match between water supply and crop needs for gravity and drip irrigation systems. Sugar beet was chosen as the target crop because of its economic importance in the region and its relatively high water requirements (El Harfi et al., 2020).

This study aims to determine whether current water-use practices are wasteful, insufficient, or adequate. It provides valuable insights on how to optimize water use, contributing to existing knowledge by offering empirical evidence on the performance of irrigation systems in a semi-arid context. The results of this study are important for policymakers and researchers seeking to improve water use efficiency in arid and semi-arid regions.

MATERIALS AND METHODS

Study area description

This study was carried out in the Tadla irrigated perimeter, located 200 km south-east of the city of Casablanca in Morocco (Figure 1). The Tadla irrigated perimeter covers a large area, estimated at 3.600 km^2 (Bouazzama et al., 2015; Chaaou et al., 2020).

The river crossed by the Oum R'bia for around 160 km. The latter divides it into irrigated sub-perimeters with different hydraulic characteristics: Béni Amir to the north (35.600 ha) and Béni Moussa (69.500 ha) to the south (Bouazzama et al., 2015; Chaaou et al., 2020).

The perimeter's climate is continental, with a dry period from April to October, and a wet period from November to March. Average annual rainfall varies from 150 to 450 mm, with an interannual coefficient of variation of 20% (Bouazzama et al., 2015; Chikhaoui et al., 2018; Chaaou et al., 2020). The wettest month is November (61.3 mm), with a secondary maximum in March (39.8 mm). July and August are the two dry months (Figure 2). The disparity of temperatures in this region is remarkable, with a maximum of 28.7 °C in July and a minimum of 10.6 °C in January.

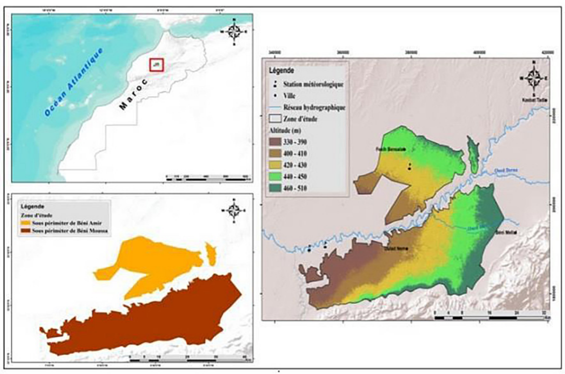

Figure 1. Location of the study area (Chaaou et al., 2020)

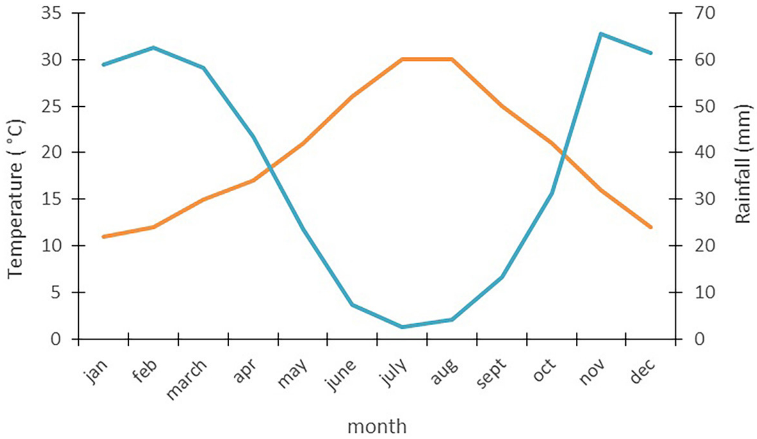

Figure 2. Umbrothermal diagram of the Tadla climatic region

The study area is divided into two different regions: Beni Moussa and Beni Amir (Figure 3). The Beni Amir perimeter is irrigated by the Ahmed Lhansali dam on the Oum Er-Rabia, with a capacity of 750 mm^3. The Beni Moussa perimeter is irrigated by the Bin El Ouidane dam, on the Oued El Abid, with a capacity of 1.500 mm^3. Groundwater consists of water tables and a turonian water table. The perimeter contains around 10.000 wells mobilizing 40% of the mobilizable volume estimated at 440 mm^3 annually (El Harti et al., 2016; Chaaou et al., 2020).

MATERIALS AND METHODS

This study was carried out for the 2022–2023 period in the two irrigated areas of Tadla.

Data collection and irrigation system

the data of the irrigation actual quantity supplied to the growers is collected by a field survey in the 2022/2023 crop year. This survey aims to collect information on the agricultural area of sugar beet plots and the irrigation system used (flood or drip) Appendix 1.

The number of sampled plots represents 30% of all beet growers. This percentage, determined by the Cosumar Group subsidiary SUTA, which is committed to preserving natural resources and biodiversity, is considered representative. The samples are distributed across the two main irrigation perimeters: Beni Amir (BA) and Beni Moussa (BM) (Fig. 4).

For the 2022/2023 crop year, the number of beet growers using drip irrigation systems in

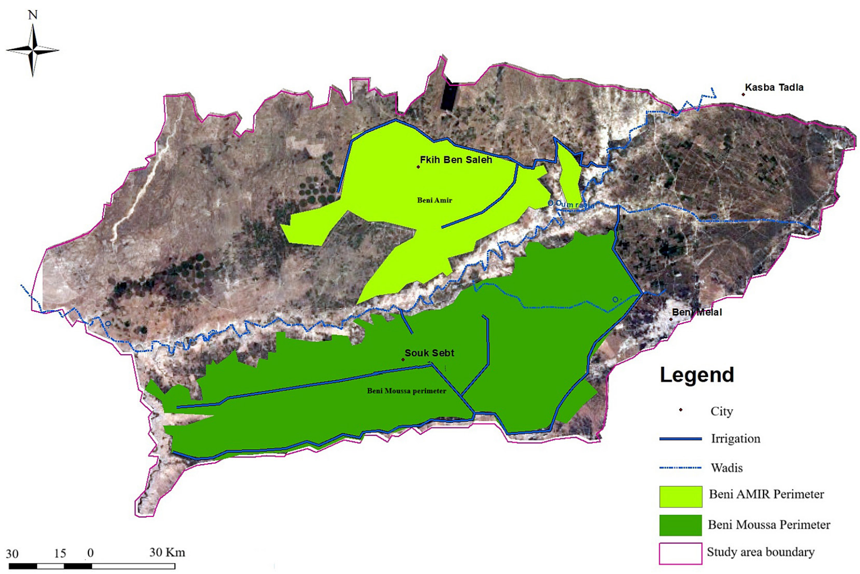

Figure 3. Location of the beni amir and beni moussa irrigation perimeters

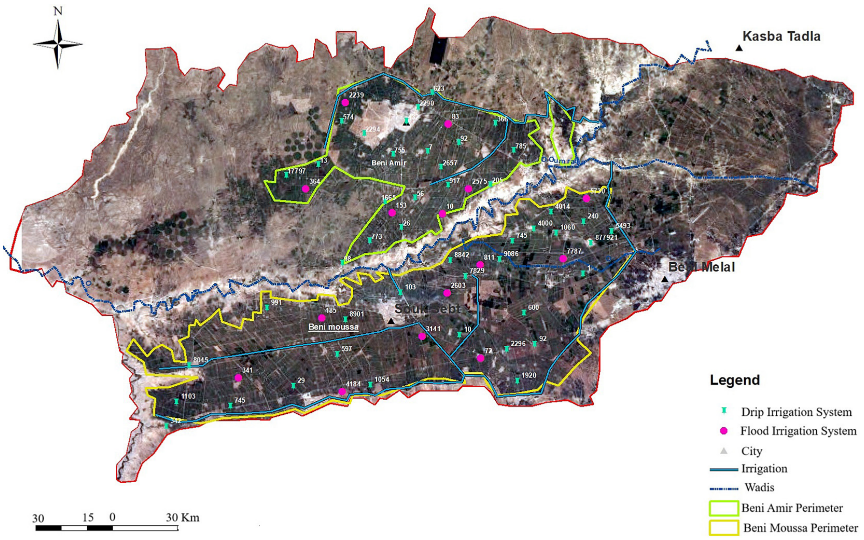

Figure 4. Distribution of samples of actual quantity of irrigation supplied and type of irrigation system

these three zones totals 152, with 66 in the BA zone and 86 in the BM zone. The total number of beet growers using drip irrigation to be surveyed is therefore 46, distributed as follows:

- Beni Amir zone: 30% of 66, i.e. 20 beet growers;
- Beni Moussa zone: 30% of 86, i.e. 26 beet growers.

In addition, the total number of beet growers using flood irrigation is 15, distributed as follows:

- Beni Amir zone: 30% of 20, i.e. 6 beet growers
- Beni Moussa zone: 30% of 30, i.e. 9 beet growers.

So, the overall total of beet growers surveyed is: 61 beet growers, The following table gives the breakdown of farmers to be surveyed by perimeter, irrigation mode and irrigation performance (Table 1).

Method used to calculate the actual amount of water irrigated by beet growers in one hectare over the entire cycle.

The amount of water consumed per hectare (Wc) is determined by the total flow used, the frequency of irrigation (i.e. the number of times farmers water their crops) and the duration of each irrigation session.

$$Wc = irrigation\ rate \times \times irrigation\ time \times irrigation\ frequency \quad (1)$$

Water requirements of sugar beet under localized irrigation in the Tadla perimeter

Calculation of ET_0

Evapotranspiration (ETo) is determined using the Blaney-Criddle formula, this method is a simplified approach to estimating evapotranspiration, using an appropriate set of meteorological data (Mohamed Abd El-Wahed and Abd El-Mageed, 2014; Xiong et al., 2015; Doorenbos et al., 2022). So the formula is as follows:

$$ETo = \left((0.457 \times T°moy) + 8.128\right) \times P \times Kt \quad (2)$$

where: *Eto* – reference evapotranspiration (mm/day); T_{moy} – mean daily air temperature (°C). It is calculated as the average of the daily maximum and minimum temperatures:

$$T_{moy} = \frac{T_{max} + T_{min}}{2} \quad (3)$$

P is the number of daylight hours on a given day as a percentage of the total number of daylight hours in a year, %.

Table 1. Number and distribution of survey plots in the tadla irrigated area

Irrigation system	Drip		Flood	
Perimeter	BA	BM	BA	BM
Number of respondents	20	26	6	9
Total	46		15	
General total	61			

$$P = \frac{Number\ of\ daylight\ hours\ in\ the\ month}{Total\ daylight\ hours\ in\ the\ year} \quad (4)$$

K_t is crop coefficient (dimensionless). This factor adjusts the formula based on the type of crop being irrigated, accounting for its specific water requirements and growth stage.

$$Kt = \left((0.031 \times T°moy) + 0.24\right) \quad (5)$$

Calculation of ETc

Crop water requirements refer to the amount of water required to meet the crop's evapotranspiration (ETc). the crop evapotranspiration, which is calculated according to FAO-56 (Allen et al., 1998), is generally obtained using a climatic approach, by applying the product of the reference evapotranspiration (ETo) multiplied by the crop coefficient (Kc) as follows: (Pereira et al., 2015)

$$ETc = ETo \times Kc \quad (6)$$

The *Kc* crop coefficients used are the FAO *Kc* coefficients (Allen et al., 1998). (see the appendix 4).

Calculation of net irrigation requirement

Net irrigation requirement is a measure used in agriculture to determine the amount of additional water needed to irrigate a given crop or area. It represents the difference between the crop's water requirements (evapotranspiration) and natural water inputs (precipitation, soil moisture, etc.) (Dukes et al., 2009). More precisely, the net irrigation requirement is calculated by subtracting the natural water supply from the crop's water needs. If natural water inputs are insufficient to meet the crop's needs, additional water must be supplied by irrigation.

To calculate the net irrigation requirement (I_N), use the following formula (Dukes et al., 2009):

$$I_N = ET_c - P_E \quad (7)$$

where: effective rainfall (P_E) refers the Precipitation falling during the growing period of the crop that is available to meet the consumptive water requirements of crops. It does not include precipitation that is lost to deep percolation below the root zone, surface runoff, or evaporation from soil surface (IA, 2005).

$$P_E = P - I_R \quad (8)$$

where: I_R – the interception of precipitation by vegetation, for our case study the interception of tight plantations (sugar beet) is 20% (Aussenac, 1968; Huttel, 1975).

RESULTS AND DISCUSSION

Water requirement for one hectare of sugar beet

Calculation of ET_0

In accordance with the Blaney-Criddle method, the results of the monthly potential evapotranspiration (ET_0) are presented in the Table 2.

Effective rainfall

The Table 3 shows the actual rainfall in the study area with the average rainfall for the 2022/2023 season and the interception:

Net water requirement for one hectare of sugar beet

Table 4 presents the cultural coefficients of sugar beet by phenological phase and the crop's evapotranspiration (ETc) values, calculated using the formula:

$$ETc = ETo * Kc * Kr \quad (9)$$

These data are used to determine the net water requirements for each month as well as for the entire growth cycle of the plant. It is worth noting that sugar beet can be sown during three distinct periods: early sowing, which occurs from September to mid-October; regular sowing, from

Table 2. Calculation of reference evapotranspiration (ETo)

Parameter	Sept.	Oct.	Nov.	Dec.	Jan	Feb	Mar.	Apr	May	June
Average T° (°C)	25.0	23.0	17.0	14.0	10.0	12.0	15.0	19.0	24.0	27.0
Sunshine duration P (%)	28%	25%	23%	22%	23%	25%	27%	29%	31%	32%
Kt	1.02	0.95	0.77	0.67	0.55	0.61	0.71	0.83	0.98	1.08
Number of days	30	31	30	31	31	29	31	30	31	30
ETo (mm)	166.71	137.66	84.13	66.77	49.80	60.40	88.41	121.25	180.58	211.61

Table 3. Effective rainfall for the 2022/2023 season

Parameter	Sept	Oct	Nov	Dec.	Jan	Feb	Mar	Apr	May	June
P (mm)	13.0	21.0	0.0	58.0	5.0	41.0	0.0	0.0	29.0	0.0
Interception	2.6	4.2	0.0	11.6	1.0	8.2	0.0	0.0	5.8	0.0
Pe (mm)	10.40	16.80	0.00	46.40	4.00	32.80	0.00	0.00	23.20	0.00

Table 4. Net requirement (m3/ha/cycle) for sugar beet in the study area

Parameter	Phenological phases									
	Germination phase		Vegetative growth phase			Root formation phase				Maturity phase
	Sept.	Oct.	Nov	Dec.	Jan	Feb.	Mar.	Apr.	May	June
kc	0.45	0.50	0.50	0.65	0.90	1.10	1.15	1.15	1.00	0.70
Kr	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
ETc (mm)	67.52	61.95	37.86	39.06	40.33	59.79	91.51	125.49	162.52	133.32
Net requirement (mm)	57.17	45.15	37.86	-7.34	36.33	26.99	91.51	125.49	139.32	133.32
Net requirement (m^3/ha/cycle)	571.17	451.48	378.59	0.00	363.34	269.92	915.07	1254.90	1393.19	1333.16
Early 4204.48										
Semi-late 4575.01										
Tardive 5529.58										

mid-October to the end of November; and late sowing, from December to February. An analysis of the data in Table 4 reveals that the net water requirement reaches its peak in May, with a value of approximately 139.32 mm (Figure 5). Depending on the sowing period, the net irrigation requirement is 4,204.48 m^3/ha for early sowing, 4,575.01 m^3/ha per cycle for regular sowing, and 5,529.58 m^3/ha per cycle for late sowing (Figure 6). Clearly, the net irrigation requirement for late-sown sugar

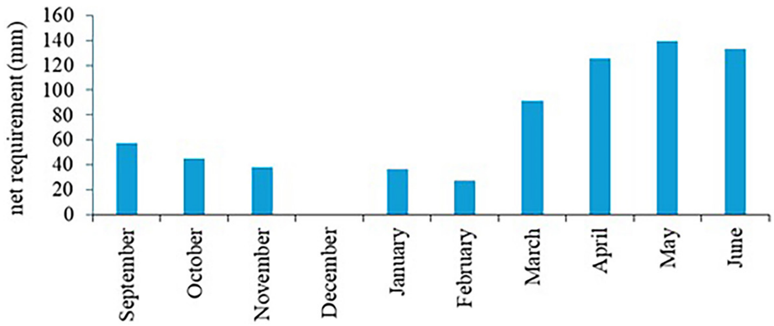

Figure 5. The net monthly requirement for sugar beet in 2022–2023

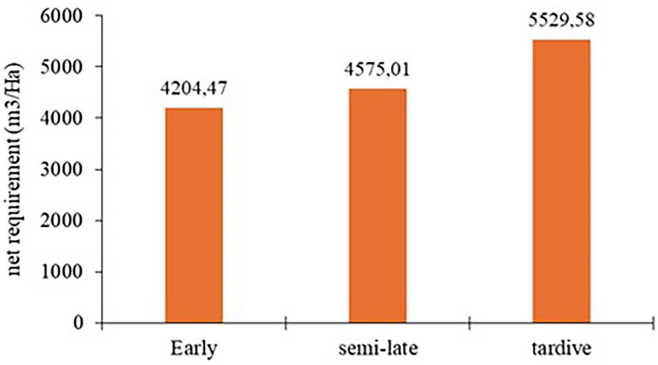

Figure 6. The net requirement of the sugar beet during the three semi-periods: early, semi-late and tardive

beet is higher than for other sowing periods. This highlights the importance of meticulous irrigation management for late-sown crops to ensure adequate water supply and optimal crop growth.

Comparison between net irrigation requirement and real quantity irrigated per hectare

Système d'irrigation goutte à goutte

On the other hand, it is alarming to note that 46% of the parcels that have adopted the drip irrigation system wastewater far exceeding the real needs of the sugar beet crop, which can lead to losses through deep percolation Assessing water wastage or deficits using drip irrigation on a hectare of sugar beet requires a detailed analysis of the amount of water applied compared to the crop's actual needs. Differentiating between net requirements and the amount of water actually used is crucial to determine whether irrigation is adequate or insufficient. The results of this assessment are presented in the table in Appendix 1.

Figure 7 reveals a concerning observation: 54% of the plots studied using the drip irrigation system experienced an irrigation deficit, indicating that the crops did not receive the required quantities of water during the agricultural period. This calls for a more detailed analysis by phenological phase to address the shortfall effectively. Conversely, 46% of the parcels using the drip irrigation system showed significant water wastage, with amounts far exceeding the actual needs of the sugar beet crop. This excessive irrigation can lead to losses through deep percolation, emphasizing the need for better irrigation management practices to optimize water use efficiency (Nassah et al., 2018). This phenomenon arises from various causes, including poor irrigation water management and improper use of the drip irrigation system. It can be attributed to the beet growers' lack of knowledge regarding the optimal timing for irrigation and the absence of a well-structured irrigation schedule.

These results highlight inefficiencies in drip irrigation caused by both farmers and water managers. Solutions include raising farmers' awareness, providing training on best practices, and promoting rational water resource management. For more information, we analyzed the percentage of excess water and irrigation deficit in the two irrigated perimeters, Beni Amir and Beni Moussa. The results obtained show that the irrigation fate of plots located in the Beni Amir perimeter is equally divided (50%) between the two components, i.e. excess water and irrigation deficit. In contrast to the Beni Amir perimeter, the percentage of excess water in the Beni Moussa perimeter was reduced by 8% recording a value of around 42%. on the other hand, the percentage of irrigation deficit exceeded 50%.

To address this water imbalance situation, the stakeholders in question must adopt the strategy of efficient irrigation to minimize water losses due to excess water by reducing the current amount of irrigation provided, on one hand. On the other hand, they should explore the possibility of implementing deficit irrigation for our sugar beet crop. Deficit irrigation strategies are one of the means to achieve better utilization of irrigation water in areas with limited water resources (Bouazzama et al., 2015; Sabri et al., 2017). This concept, proposed by Chalmers et al. (1981), is based on controlling the vegetative growth of the crop under controlled deficit irrigation without reducing the yield (Fig. 8).

Flood irrigation system

From the data presented in Appendix 2, we can see that 100% of the plots studied were wasting

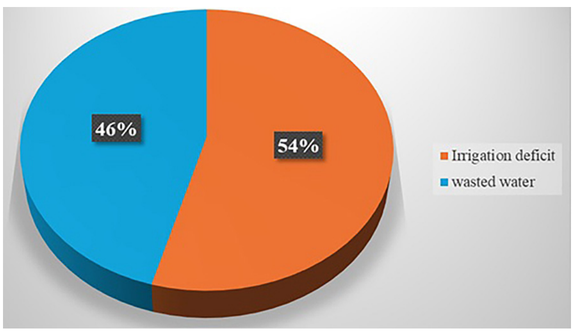

Figure 7. The current state of drip irrigation in the Tadla irrigated perimeter

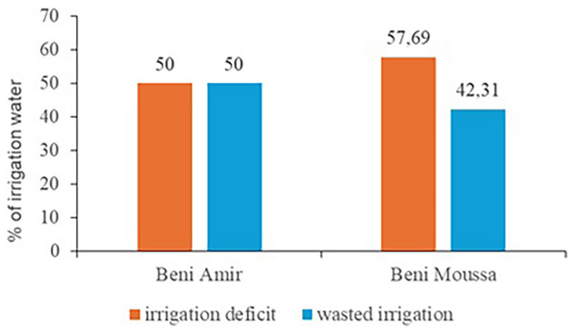

Figure 8. The current state of drip irrigation in the two irrigated areas of beni amir and beni moussa

water. This situation is due to the absence of a well-structured irrigation program and sensors to determine the net requirements of the crop at the time of irrigation, forcing beet growers to resort to wasting water as the sole means of satisfying the demands of their crops. To help farmers assess the irrigation efficiency of their orchards, a new multicriteria approach based on the analytic hierarchy process (AHP) technique and the participation of a group of experts is proposed (Poveda-Bautista et al., 2021). The conversion from gravity irrigation to localized irrigation must take place under favorable conditions within the irrigated perimeter of Tadla.

CONCLUSION

Our study demonstrated the superior efficiency of the drip irrigation system compared to the flood-fed system, based on the analysis of total water consumption per hectare irrigated by both systems. However, under current drought conditions, neither system can fully meet the challenges of irrigation if farmers fail to align water application with plant needs. This study confirms a critical finding: a significant gap exists between the actual quantity of water applied and the net irrigation requirements of plants. This mismatch leads to considerable water wastage, highlighting the urgent need for optimized irrigation management during drought periods. The results underscore the importance of water conservation as a key strategy to ensure the survival and sustainability of crops under water-scarce conditions. Among the potential solutions, deficit irrigation strategies offer a promising approach to optimizing water use in regions with limited water resources, without compromising crop yields. Previous studies have extensively documented the effectiveness of deficit irrigation in various fruit orchards, including peach (Chalmers et al., 1981), pear (Zhao et al., 2015), almond (Razouk et al., 2013), mandarin (Pedrero et al., 2014), clementine (Ballester et al., 2014), and apricot (Pérez-Pastor et al., 2014). Furthermore, our findings suggest that deficit irrigation could also be successfully applied to sugar beet cultivation, offering a pathway to more sustainable water management in agriculture.

Acknowledgements

This research was carried out at the Private university of Marrakech (http://UPM.ac.ma) and the GEOHYD laboratory (Cadi Ayyad University). thank the Regional Office of Agricultural Development of tadla (ORMVAT), and I would like to thank Mr. Zitouni Abdulrazak as a student for his brilliance and Moroccan farmers for their collaboration.

REFERENCES

1. Al Hamedi FH, Karthishwaran K, Yongming L, Maozhi R, Abdul J, Mohammed Abdul MA. (2023). Wastewater irrigation: A promising way for future sustainable agriculture and food security in the united arab emirates. J. Water. 15(12): 2284. https://doi.org/10.3390/w15122284
2. Allen RG, Pereira LS, Raes D, Smith M. (1998). Crop Evapotranspiration—Guidelines for Computing Crop Water Requirements. Food and Agriculture Organization. Rome, Italy: 1998.
3. Ballester C, Castel J, Abd El-Mageed TA, Castel JR, Intrigliolo DS. (2014). Long-term response of ‘Clementina de Nules’ citrus trees to summer regulated deficit irrigation. J. Agricultural Water Management 138: 78–84. https://doi.org/10.1016/j.agwat.2(014.03.003
4. Banque M. Rapport Climat et Développement au Maroc, Octobre 2022, 4.
5. Benoit, G. and Comeau, A. (2006). A Sustainable future for the mediterranean, the blue plan’s environment and development outlook, Plan Bleu.
6. Bouazzama B, Bouaziz A, Xanthoulis D, Bahri A. (2015). Effet du déficit hydrique sur la croissance, le rendement et l’efficience d’utilisation de l’eau chez la luzerne. Rev. Mar. Sci. Agron. Vét. 3(2): 16–26.
7. Chaaou A, Chikhaoui M, Naimi M, El Miad A, Achemrk A. (2020). Cartographie du risque de salinité des sols à l’aide de l’approche des indices et des données multi-sources : Cas de la plaine de tadla au maroc. European Scientific Journal. 16(33) : 206. https://doi.org/10.19044/esj.2020.v16n33p206
8. Chalmers DJ, Mitchell PD, Van Heek L. (1981). Control of peach tree growth and productivity by regulated water supply, tree density, and summer pruning. Journal of the American Society for Horticultural Science. 106: 307–312
9. Chehbouni, A., Escadafal, R., Duchemin, B., Boulet, G., Simonneaux, V., Dedieu, G., Mougenot, B., Khabba, S., Kharrou, H., Maisongrande, P., et al. (2008). An integrated modeling and remote sensing approach for hydrological study in arid and semi-arid regions: the SUDMED Programme. Int. J. Remote Sens. 29(17–18), 5161–5181. http://dx.doi.org/10.1080/01431160802036417
10. Chikhaoui M, Naimi M, Chaaou A. (2018). Développement d’un indice de risque de salinité des sols à l’aide

du capteur Sentinel-2 et des données multi-sources: Cas de la plaine de Tadla au Maroc. International Workshops sur l'apport des images Sentinel pour le développement, 6–7 mars 2018, CRTS-Rabat, Maroc.

11. Doorenbos J, Pruitt WO. (1977). Guidelines for Predicting Crop Water Requirements. FAO; Rome, Italy. (Irrigation and Drainage Paper FAO-24). https://www.fao.org/publications
12. El Harfi, M., El Amrani, N., & Hachicha, M. (2020). Optimisation de l'irrigation de la betterave sucrière dans les régions semi-arides : cas de la région de Tadla au Maroc. Revue des Sciences de l'Eau, 33(2), 145–157. http://dx.doi.org/10.7202/1066178ar
13. El Harti A, Lhissou R, Chokmani K, Ouzemou JE, Hassouna M, Bachaoui EM, El Ghmari A. (2016). Spatiotemporal monitoring of soil salinization in irrigated Tadla Plain (Morocco) usinsatellite spectral indices. International Journal of Applied Earth Observation and Geoinformation. 50: 64–73.
14. English MJ, Raja SN. (1996). Perspectives on deficit irrigation. Agricultural Water Management. 32: 1–14.
15. Hamdy A, Cosimo L. (2005). Coping with Water scarcity, in the Mediterranean, What, Why, and how. Water Resources in Arid and Semi-Arid Regions. CIHEAM-IAMB, Bari, Italy.
16. Kahil, M. T., Dinar, A., & Albiac, J. (2015). Modeling water scarcity and droughts for policy adaptation to climate change in arid and semi-arid regions. Journal of Hydrology, 522, 95–109. http://dx.doi.org/10.1016/j.jhydrol.2014.12.042
17. Khalid F, EL Moujahid L. (2023). la gestion de l'eau au maroc: vers un nouveau mode de gouvernance. revue droit and societe. social and media studies institute. 2737–8101.
18. Kobry A.E. (2004). L'irrigation localisée dans les périmètres de grande hydraulique, atouts et contraintes dans le périmètre du Tadla au Maroc. Séminaire sur la modernisation de l'agriculture irriguée, 2004, Rabat, Maroc. 11. ffcirad-00189142f
19. Le Ministre de l'Agriculture, de la Pêche Maritime, du Développement Rural et des Eaux et Forêts, le plan Maroc vert : bilan et impact 2008–2018, 9, 2020.
20. Mohamed H, Abd El-Wahed T, Abd El-Mageed A. (2014). Estimating reference evapotranspiration using modified Blaney-Criddle equation in arid region. Bothalia Journal, 44(7).
21. Pedrero F, Maestre-Valero JF, Mounzer O, Alarcón JJ, Nicolás E. (2014). Physiological and agronomic mandarin trees performance under saline reclaimed water combined with regulated deficit irrigation. Agricultural Water Management. 146: 228–237. https://doi.org/10.1016/j.agwat.2014.08
22. Pérez-Pastor A, Ruiz-Sánchez MC, Domingo R. (2014). Effects of timing and intensity of deficit irrigation on vegetative and fruit growth of apricot trees. Agricultural Water Management. 134: 110–118. https://doi.org/10.1016/j.agwat.2013.12.007
23. Razouk R, Ibijbijen J, Kajji A, Karrou M. (2013). Response of peach, plum and almond to water restrictions applied during slowdown periods of fruit growth. American Journal of Plant Sciences. 4: 561–570. https://doi.org/10.4236/ajps.2013.43073
24. Sabri A, Bouaziz A, Hammani A, Kuper M, Douaik A, Badraoui M. (2017). Effet de l'irrigation déficitaire contrôlée sur la croissance et le développement foliaire du palmier dattier (Phoenix dactylifera L.). cahiers d'agriculture. 26, 55005. https://doi.org/10.1051/cagri/2017033
25. Saraiva A, Presumido P, Silvestre J, Feliciano M, Rodrigues G, Oliveira P, Silva E, Damásio M, Ribeiro A, Ramôa S, Ferreira L, Gonçalves A, Ferreira A, Grifo A, Paulo A, Castro Ribeiro A, Oliveira A, Dias I, Mira H, Amaral A, Mamede H, Oliveira M. (2020). Water footprint sustainability as a tool to address climate change in the wine sector: a methodological approach applied to a Portuguese case study. Atmosphere. 11(9): 934.
26. World Bank. (2007). Making the Most of Scarcity: Accountability for Better Water Management Results in the Middle East and North Africa; MENA Development Report; World Bank: Washington, DC, USA.
27. World Bank. (2003). The water resources sector strategy: an overview – managing and developing water resources to reduce poverty. 24
28. Xiong Y, Luo Y, Wang Y, Traore S, Xu J, Jiao X, Fipps G. (2015). Forecasting daily reference evapotranspiration using the Blaney-Criddle model and temperature forecasts. Arch. Agron. Soil. Sci. 62: 790–805. https://doi.org/10.1080/03650340.2015.1083983
29. Zhao Z, Wang W, Wu Y, Xu M, Huang X, Ma Y. (2015). Leaf physiological responses of mature pear trees to regulated deficit irrigation in field conditions under desert climate. Scientia Horticulturae. 187: 122–130. https://doi.org/10.1016/j.scienta.2015.03.009