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Effect of water-nitrogen interaction on sugar beet yield under localized irrigation in a semi-arid region

Nora TOUFIKI [1], Nadya WAHID [1], Ilhame ELMAJETNI [1], Younes OULLUOSSEAT [1], Bassou BOUAZZAMA [2]

[1]Sultan Moulay Slimane University, Faculty of Science and Techniques, Environmental Engineering Laboratory, Ecology, and Agro-Industrial Valorization, Ecology and Sustainable Development Team, Beni Mellal, Morocco.
[2]National Institute of Agronomic Research, Regional Center for Agronomic Research of TADLA, BP 567 Béni Mellal, Morocco.

***Corresponding author: bassou.bouazzama@inra.ma**
https://orcid.org/0009-0000-8606-3085

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Abstract: The study of the response of sugar crops to water and nitrogen deficit is important in areas where water resources are very limited. This work aims to study the response of sugar beet to water stress and fertilization under different levels of nitrogen fertilizers installed in the semi-arid climate of the Tadla irrigated area. The study focused on four water regimes represented by irrigation at 100%, 80%, 60% and 40% ETc of the water requirements of the beet and four levels of nitrogen fertilization (80 kg N/ha, 160 kg N/ha, 240 kg N/ha and 320 kg N/ha) applied by fertigation with a splitting of input according to the nitrogen assimilation curve by the beet plant. The results of the experiment showed that water stress significantly induced a decrease in leaf area and stomatal conductance, as well as a decrease in root yield. However, a water regime of 80% ETc represents a good compromise between saving water and maintaining satisfactory yields. In conditions of lack of irrigation water, a tolerable level of water stress is 60% to ensure a satisfactory productivity rate. The nitrogen supply shows that its increase, in the case of a previous crop of beans, leads to the application of high doses of nitrogen. The leaf area and root yield reach their maximum at the level of the 4 water regimes from the dose 160 kg N/ha, also with an approximate optimal dose of 80 kg N/ha for the case of the previous legume crop. Splitting nitrogen inputs helps to limit high concentrations in the soil and delay its migration to depth, thereby reducing losses through leaching.

Keywords: Sugar beet, Water stress, Water use efficiency, N fertilizer, fertigation, semi-arid.

Introduction

Sugar beet (*Beta vulgaris L.*) is a crop of strategic importance in international and national sugar production. This plant is drought resistant, producing a satisfactory yield even with reduced irrigation (Yuan et al., 2004; Abyaneh et al., 2017; Hongliang et al., 2024). Sugar beet is a type of beet grown for its fleshy root used mainly for sugar production. It is a plant that adapts to a wide range of climatic conditions. It is moderate to soil water stress, but also it is sensitive to water deficit in the initial phase during emergence and in the early stages of development (Martin, 1983). This crop is one of the most water-consuming plants due to its long growth cycle. The water requirements of sugar beet cultivation are highly dependent on weather conditions, irrigation management and growing season, plant density, genotypes and nitrogen supply (Varga et al., 2022). In Morocco, sugar beet is a very popular crop in semi-arid and arid regions, such as the Tadla area. However, in arid and semi-arid climatic zones, sugar beet irrigation is a limiting factor in basic agronomic management (Topak et al., 2011; Barzegari et al., 2017). This limiting factor is worsening with climate change. In the last three years in Morocco, climate changes leading to drought have been observed more frequently, including increased air temperature and scarcity of annual precipitation. In addition, yields can fluctuate from one season to another, leading to difficulties in planning sugar production and financial pressure for farmers.
The results of many studies report yield losses under water deficit conditions (Ober at al., 2005; Abyaneh et al., 2017; Varga el al., 2022; Hongliang et al., 2024). Localized irrigation, especially in semi-arid areas, offers more precise management of water resources. By controlling water supply directly to the root zone, this technique improves irrigation efficiency, reduces evaporation losses and allows water availability to be modulated according to the plant's needs. However, the efficiency of this irrigation method also depends on nitrogen fertilization (Varga el al., 2022). In addition, water constraints combined with nitrogen deficiency at the end of the cycle slow down root development and increase the final sugar concentration (Campbell et al, 1967; Varga et al., 2022). Nitrogen, as an essential element for plant growth and development, directly influences photosynthesis, protein synthesis and; therefore, final yield. Its interaction with water availability is critical, as an excess or deficit of either can harm plant growth and nutrient absorption. Hence the importance

of properly controlling nitrogen fertilization with the introduction of new water and energy saving technologies related to irrigation systems to improve root yield and preserve soil quality.

The impact of nitrogen on sugar beet yield is necessary since nitrogen is a key element in leaf and root growth (Cook and Scott, 1994). In addition, adequate nitrogen fertilization stimulates sugar production in sugar beet, which is crucial for its profitability (Moughli, 2019). In Morocco, sugar crop fertilization strategies consist of basal and top-dressing fertilizer applications. Basal fertilizers consist of a portion of the nitrogen dose and the total doses of phosphorus and potassium. These inputs were determined based on the results of soil fertility analyses. Even during the growing seasons, when weather conditions are favorable for sugar beet production, water deficits can occur due to high air temperature values in semi-arid areas throughout the cycle, and consequently intense evapotranspiration during the summer months. Well-managed drip irrigation and nitrogen fertilization guarantees an increase in beet productivity while reasoning the supply of water and nitrogen fertilizers as well as obtaining better uniformity of yield year after year, especially in the presence of drought occurrence problems caused by climate change. Therefore, the aim of this study is to determine the impact of the interaction between water and nitrogen on the root yield of sugar beet grown under a water-saving system (e.g; drip). The results of this study could encourage farmers to manage irrigation and reason fertilization more efficiently and industrialists to plan sugar production well.

Results

Water requirement of sugar beet cultivation in semi-arid regions

At the end of the 2021/2022 sugar beet growing season in the semi-arid region of Tadla, the total volume of water consumed by the plant according to the water regimes (T1: 100% ETc, T2: 80% ETc, T3: 60% ETc and T4: 40% ETc) is shown in Figure 1. Sugar beet water requirements increased in advance of the crop cycle and according to climatic demand for a total volume of water consumed. The total irrigation volume decreased proportionally to the reduction in the water regime. Thus, for each reduction of 20% in the regime compared to the 100% ETc reference regime, the volume of water during the experimental period is reduced by approximately 100 mm. This linear relationship indicates well-controlled irrigation management according to the different water deficit scenarios. The 80% ETc regime, which uses 80% of the water volume of the full regime, could represent an interesting compromise between saving water and maintaining an acceptable yield. It allows reducing water consumption by 102.6 mm compared to the full regime, while potentially preserving a good part of the agricultural yield. The 60% ETc and 40% ETc regimes, which significantly reduce the water supply, risk not meeting the water needs of the plant during the critical phases. The challenge is to find a balance between saving water and preserving yields of crops such as sugar beet, which is a very water-intensive crop.

Useful water reserve for sugar beet cultivation in semi-arid regions

Figure 2 represents the soil moisture tension at different depths 30, 60 and 100 cm under regimes T1 and T4. The general variation profile of the tension of the two water regimes (T1 and T4) as a function of depth shows an increase in moisture before each irrigation followed by a decrease in the days following irrigation or precipitation. The data shows the variations of soil tension in the two irrigation regimes, with marked differences between the 40% and 100% irrigation regimes at different depths.

The irrigation regime at 40% ETc shows much higher tensions, especially at 60 cm and 100 cm, reaching 76 and 74 cbar, respectively. These high tensions indicate a significant water deficit in these deep layers, suggesting that the water supplied by irrigation does not reach the roots located at depth. On the other hand, at 30 cm, although the tension remains relatively low at the beginning, it gradually increases with time, suggesting increasing dryness in this superficial layer as well. This directly affects the absorption of water by the superficial roots, leading to significant water stress. This explains that the plant is stressed due to the lack of precipitation which coincides with unsatisfactory water resources existing in the storage basin. For the 100% ETc regime, a better distribution of moisture is observed in the different layers of the soil. Soil moisture tension remains relatively low (indicating better water availability) in all three layers, particularly at 60 cm and 100 cm, where tension is almost zero at certain dates. This indicates that the soil in the deeper layers (60 cm and 100 cm) remains well irrigated, allowing continuous water absorption by the deep roots of the beet. The high tension at 30 cm observed at the end of the period (up to 72 cbar) could be attributed to increased evaporation or increased water consumption by the plant in the surface layer.

The results obtained by monitoring the evolution of humidity under the two water regimes (T1 and T4), showed that increasing depth generates excessively high-tension values measured by the manometer. This means that even if the useful reserve (UR) of the soil increases with depth, the beet crop does not tend to use them easily because of their root systems which do not exceed 60 cm (Fig 2).

The effect of water stress on stomatal conductance

Figure 3 shows the evolution of stomatal conductance of sugar beet as a function of cultivation duration, under different water stress regimes. The analysis of Figure 3 shows a progressive decrease in stomatal conductance with time for each water regime. The reduction being more marked in the more severe water stress regimes (60% ETc and 40% ETc). In fact, for 100% ETc irrigation, stomatal conductance decreases slightly from 60 $mmol/m^2/s$ to 49 $mmol/m^2/s$ as the crop progresses. Fewer than 80% ETc irrigation, a similar trend is observed, although the values are slightly lower than those of the 100% treatment. At more severe water stress levels (60% ETc and 40% ETc), stomatal conductance drops more markedly, with values dropping from 57 $mmol/m^2/s$ to 31 $mmol/m^2/s$ for the 60% ETc regime and from 50 $mmol/m^2/s$ to 30 $mmol/m^2/s$ for the 40% ETc regime. This explains why sugar beet during drought conditions closes its stomata to avoid water loss through the phenomenon of transpiration, which serves the emission of water in the form of vapor.

Effect of water stress on the leaf cover of beet

The difference in canopy cover evolution is remarkable for the two water regimes (Fig 4). The 100% ETc regime has significantly higher canopy cover values than the 60% regime, but it reaches the maximum value on day 137 after sowing. Therefore, water stress slows down the plant growth of sugar beet in semi-arid conditions of Tadla.

Nitrogen requirements and effect of nitrogen on leaf area for sugar beet under semi-arid conditions

The quantities of nitrogen supplied for each water regime are: 80 kg N/ha (D1); 160 kg N/ha (D2); 241 kg N/ha (D3) and 320 kg N/ha (D4). Figure 5 shows the evolution of the quantity of nitrogen applied at the experimental plot level according to the rate of its absorption. The kinetics of nitrogen absorption increases as growth progresses. This increasing kinetics is higher for high fertigation doses (D4> D3> D2> D1). The effect of different doses of nitrogen on the leaf area of sugar beet under two regimes T1 and T4 is given in Figure 6. It appears that the reduction in leaf area is closely linked to water deficit and nitrogen fertilization. The analysis of Figure 6 shows that the leaf area

Table 1. Dosage of nitrate (NO^{-3}) and ammonium (NH^{+4}) leached at the two water regimes 100% and 60% (growing season 2020/21).

Water regime	NO^{-3} (ppm)	NH^{+4} (ppm)
60% ETc	98	11
100% ETc	553	91

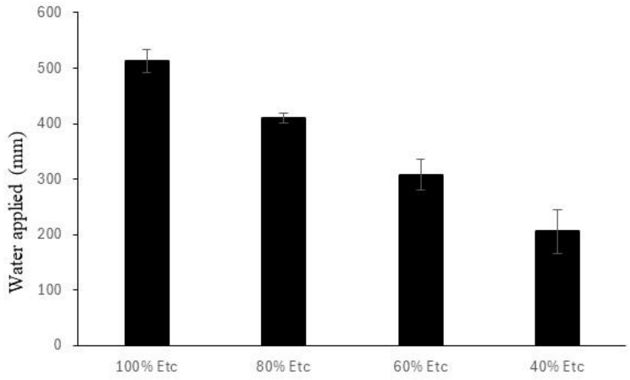

Fig. 1. Volume of water applied by water regime (growing season 2021/2022).

Table 2. Climatic data of the experimental station in the growing periods of 2021 and 2022.

Growing year/month	1st growing year (2020/21)				2nd growing year (2021/2022)			
	Mean Tmax (°C)	Mean Tmin (°C)	Total precipitation (mm)	ET0 (mm/d)	Mean Tmax (°C)	Mean Tmin (°C)	Total precipitation (mm)	ET0 (mm)
Octobre	29.1	11.7	23	3.1	32.0	11.9	0	2.9
November	25.1	9.9	40	2.1	21.8	5.6	11	1.6
December	19.7	5.0	20	1.4	21.6	5.2	26	1.2
January	19.1	4.3	59	1.6	22.2	3.9	0	1.5
February	21.7	6.1	55	2.4	24.7	6.0	7	2.4
March	24.0	7.2	65	3.5	20.8	7.2	72	2.9
April	26.4	9.9	28	4.4	25.4	9.0	22	4.5
Mai	32.5	13.7	17	5.8	34.3	13.9	0	6.0
June	33.3	15.8	0	6.3	36.2	17.6	0	6.7

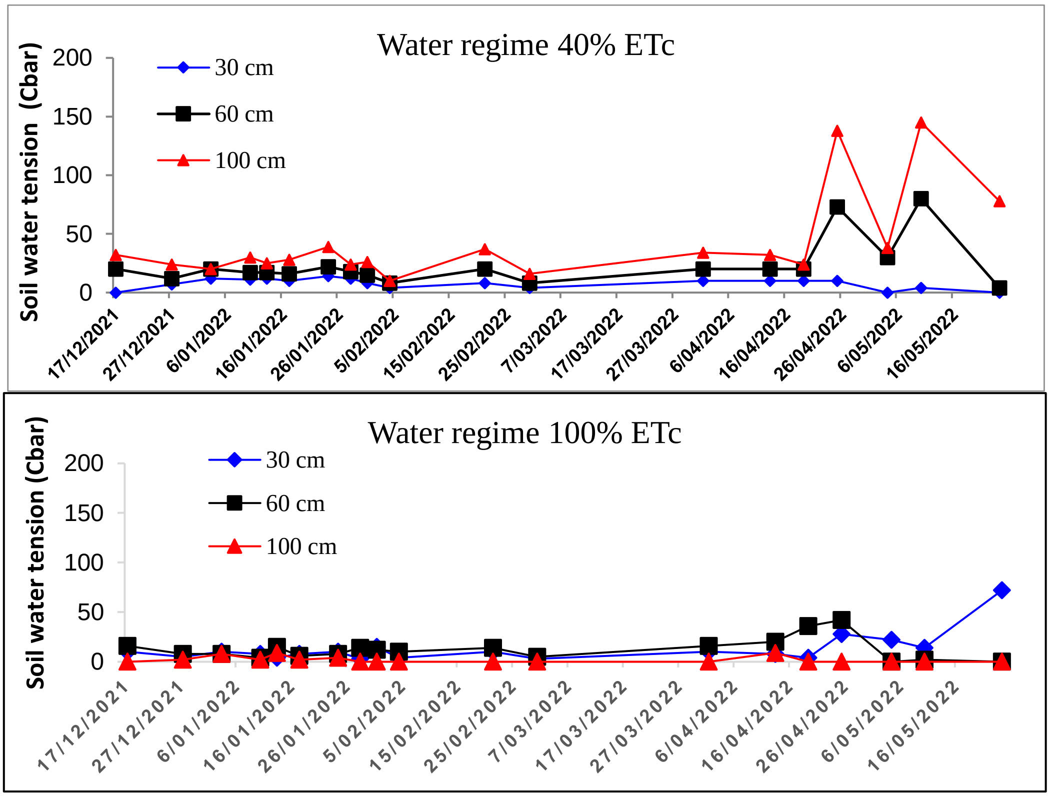

Fig. 2. Illustration of soil water tension at different depths under extreme water regimes 40% ETc and 100% ETc.

Table 3. Physicochemical compositions of the soil of the experimental plots at the level of the CRRA experimental area of Afourer du Tadla in Morocco.

Depth (cm)	clay (<0.002 mm) (%)	Silt (0.002 mm) (%)	Sand (0.05-2.0 mm) (%)	Organic matter (%)	Saturated soil pH	Electrical conductivity of saturated soil (mS/cm)
0-30	27.7	54.3	18.0	1.91	7.97	1.03
30-60	43.3	17.9	38.8	1.08	8.22	0.45
60-90	47.4	35.2	17.4	1.08	8.43	0.53

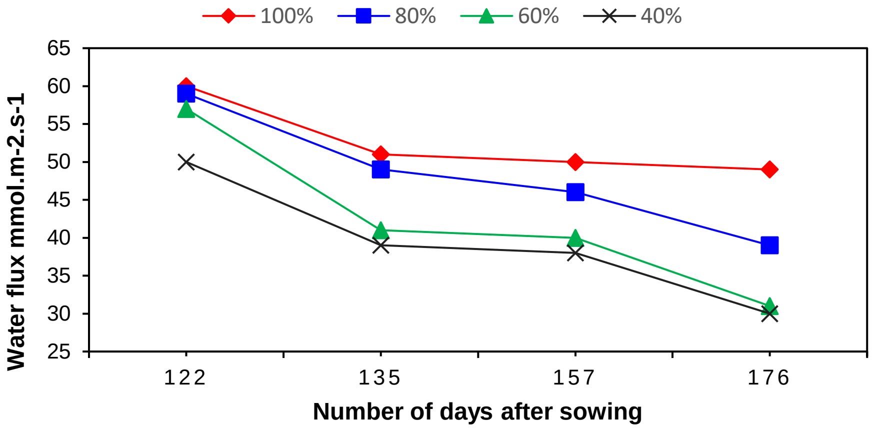

Fig. 3. Variation of stomatal conductance as a function of the duration of sugar beet cultivation under water stress regimes.

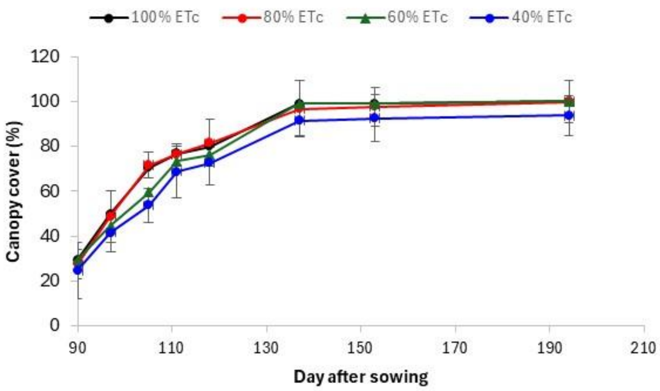

Fig. 4. Effect of water stress on the leaf cover of sugar beet under water regimes compared.

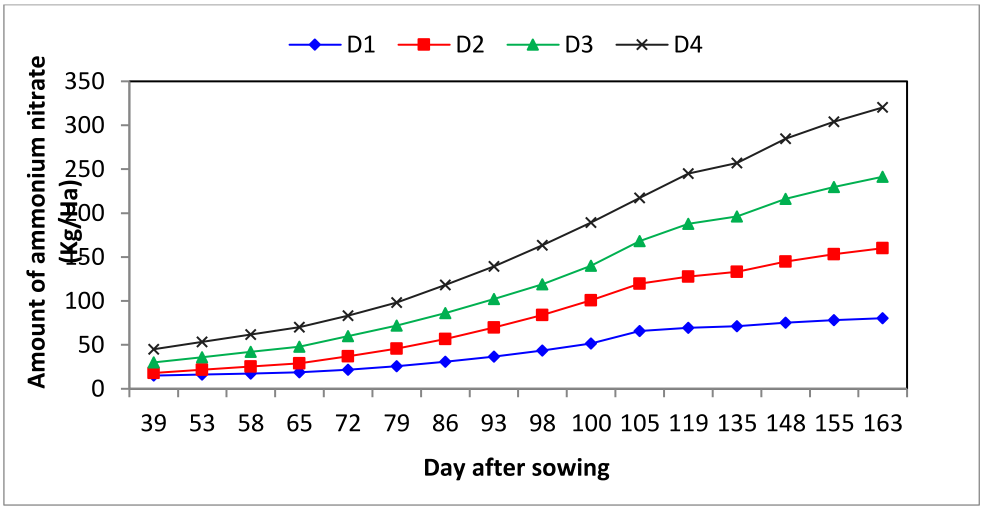

Fig. 5. Ammonium nitrate accumulation during growth at different fertilization levels.

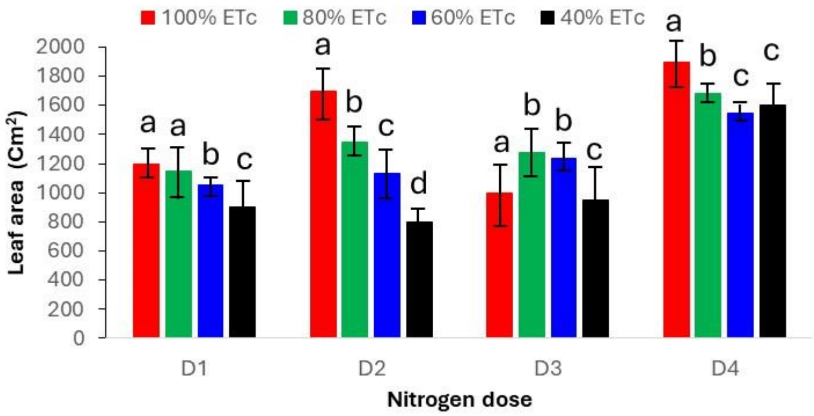

Fig. 6. Evaluation of the effect of nitrogen fertilization on the leaf surface of sugar beet in a semi-arid region.

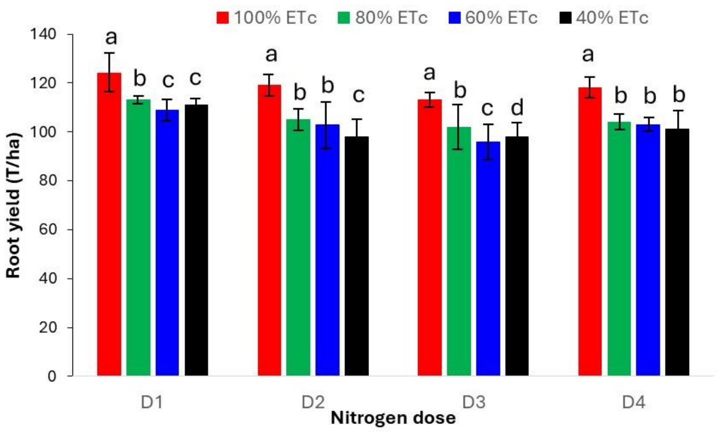

Fig. 7. Presentation of the root yield of sugar beet grown in semi-arid regions as a function of the nitrogen dose under different water regimes.

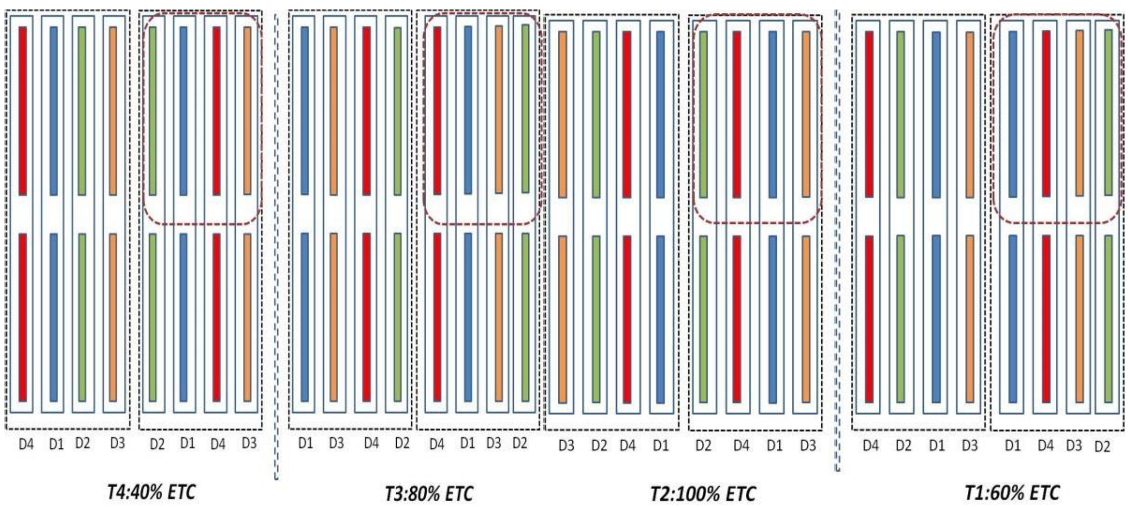

Fig. 8. Experimental design to test the effect of nitrogen fertigation on beet quality in the semi-arid zone of Tadla in Morocco.

of the plant increases as a function of the added dose for both water regimes, with the exception of treatment D3 which is low. Thus, the application of high doses of nitrogen shows a significant response in leaf area, in which the higher the dose the more the leaf area is increased. This is the case for D4: 320 kg N/ha. The leaf area of sugar beet is slightly high between water regime T1 (100% ETc; 1,900 cm^2 per plant), and that of T4 (40% ETc) which reaches 1,600 cm^2. However, the analysis of the drainage water shows that the leaching is rich in nitrate (553 ppm) for the 100% ETc water regime in comparison with that of 60% ETc (98 ppm) (Table 1). This means that the 100% ETc water regime influences groundwater through nitrate pollution and could cause a decrease in leaf area.

Effect of fertigation on root yield of beet in semi-arid region

The fresh weight of root yield of sugar beet at different doses of nitrogen in the 100% ETc water regime, are higher than those of the same treatment in the 80% ETc, 60% ETc and 40% ETc water regimes, respectively (Fig 7). The root yield within the 100% ETc water regime reached its maximum, which is 127.6 T/ha. Also, there is a decrease in root yield about 9% on average, when moving from the 100% ETc water comfort regime to the 40% ETc stressed regime (Fig 7). The difference in root yield between the water regimes is significant ($P < 0.0001$).

Effect of fertigation on root yield of beet

For the nitrogen effect, it is noted that the root yield reaches its maximum at the level of the 4^{th} water regimes from the dose D1 (80 kg N/ha), with which the yield reaches 124.2 T/ha at the level of water regime 100% ETc and 117.6 T/ha for the water regime 40% ETc (Fig 7). It is noted that for the four water regimes, the dose of nitrogen that ensures the best root yield is D1: 80 kg N/ha. The effect of the previous legume crop had a significant effect associated with nodules and nitrogen-fixing bacteria, generating a nitrogen stock of approximately 80 kg N/ha in the soil.

Discussion

Sugar beet is a water-intensive crop, which poses challenges in semi-arid regions, such as the Tadla region of Morocco. This crop is sensitive to water stress, especially during critical periods of its growth cycle. Analysis of the response of sugar beet to different irrigation regimes and management of nitrogen requirements in these regions are essential to optimize water and nitrogen use while maintaining acceptable yields. The total volume of water consumed by sugar beet decreases linearly with the reduction of the water regime, with a decrease of approximately 100 mm for each 20% reduction in the reference water regime. The present study shows that the 80% ETc (T2) water regime appears to be an optimal compromise, allowing reducing water consumption, while maintaining relatively high yields. However, the more severe regimes, at 60% ETc and 40% ETc, may not be sufficient to meet the plant's needs during critical phases, which could have significant consequences on the production. Sugar beet could rapidly absorb water and resume normal growth when water supply is sufficient (Barbanti et al., 2007; Li et al., 2019). This result indicates that water is used more efficiently under reduced water regimes, but at the risk of compromising yields, if critical water needs are not met.

Thus, the study carried out on the distribution of humidity in the soil at different depths (30, 60 and 100 cm) shows that the 100% ETc water regime shows a better distribution of humidity, with low water tensions in all layers, promoting water absorption by the roots. Conversely, the 40% ETc water regime promotes higher water tension, particularly at depths of 60 and 100 cm. This suggests that the water supplied by irrigation does not reach deep layers of the soil, which could harm water absorption by the roots of the beet, particularly during the periods of drought. The water drought created at 60% ETc and 40% ETc, contributed to the reduction of stomatal conductance. This closure of the stomata is a defense mechanism of the plant to limit water losses by transpiration. However, this reduction in stomatal conductance can also limit gas exchange and photosynthesis, affecting the plant growth (Ober et al., 2005; Esmaeili, 2011; Steduto et al., 2012). Under 100% ETc and 80% ETc water regimes, stomatal conductance decreases slightly, but remains at an acceptable level to maintain normal physiological activity promoting better leaf area and leaf cover. The reduction in leaf area by water stress may be due to a decrease in epidermal cell activity that results in a reduction in the total number of cells in the leaf (Matthews, 1986). Monitoring the evolution of plant canopy cover has shown a reduction in leaf area at the stressed water regime. For fertilization, the results show that as the dose of nitrogen provided increases, the canopy cover increases to the detriment of the dry matter of the roots.

Nitrogen application is essential to maximize sugar beet growth and yield. The study of the effect of nitrogen in fertigation shows that the most effective nitrogen dose to maximize leaf area and root yield is 80 kg N/ha (D1), regardless of the water regime. However, nitrogen leaching, observed especially under the 100% ETc water regime, could contribute to groundwater pollution, raising environmental concerns. Therefore, nitrogen management must be optimized to avoid over-fertilization, particularly in high water regimes where excess water could lead to nitrogen losses through drainage. Adjusting nitrogen doses according to water regimes helps reduce pollution and ensure optimal plant uptake. The fractionation of nitrogen inputs was applied according to the nitrogen assimilation curve by sugar beet which allows to limit the high concentrations of nitrogen in the soil solution and to delay its migration in depth. It also promotes a better adjustment of soil conditions to the instantaneous requirements of the plants and allows to reduce the potential of leaching.

Low soil water content leads to decreased N migration from soil to sugar beet taproots (Guo et al., 2012), and high soil water content promotes increased N uptake by plants (Ma et al., 2021). However, this does not mean that adequate water and N supply is the best option, because frequent irrigation and high irrigation rates still leach N into the deeper soil layer, resulting in reduced available N around the roots (Barbanti et al., 2007; Quemada and Gabriel, 2016).

The results of root yield as a function of fertigation under different water regimes show a significant reduction in root yield as the water regime decreases, with an average decrease of 9% in yield when moving from 100% ETc to 40% ETc water regimes. However, even under reduced regimes, adequate nitrogen application allows relatively high root yields to be maintained, highlighting the importance of combining water management with appropriate fertilization to optimize production in semi-arid conditions. It could be suggested that for the four water regimes studied, the nitrogen dose that ensures the best root yield is D2: 160 kg N/ha. The effect of the previous legume crop has a significant effect, having roles in the association of nodules and nitrogen-fixing bacteria, which generates a nitrogen stock of approximately 80 kg N/ha in the soil (Bouazzama, 2000).

Materials and Methods

Plant materials
In this experiment the widely cultivated monogerm sugar beet genotype (Dynamic) was used.

Experimental site
A field experiment was conducted in 2021-2022 at the agrometeorological experimental station of the regional center for agricultural research (CRRAT) of Tadla in Morocco. The Tadla region is characterized by an arid to semi-arid climate. The average annual rainfall of the perimeter is 350 mm, the average annual evaporation is of the order of 1,800 mm and the temperatures experience significant variations with a maximum in August of 46 °C and a minimum in January of 3 °C. These data on precipitation and air temperature during the sugar beet growing seasons were collected from the automatic weather station of the experimental site in CRRE (Table 2). Before planting, the physicochemical properties of the soil layer taken from 0 to 90 cm were measured (Table 3). The soil texture was clay-silty (0-90 cm, Table 2). At the 0-30 cm layer, the organic matter content was 1.91%, the basic pH was 7.97.

Experimental design
In 2021 and 2022, the trial was carried out according to a Split-plot design. The cycle of the experimental trial was 230 days (Sowing was on 10/27/2021 until uprooting on 06/13/2022). The area of the experimental plot is 0.76 ha. The experimental device is divided into 4 plots to test four water regimes defined by coefficients of reduction of sugar beet water requirement (ETc) and represented by 100% ETc (T1), 80% ETc (T2), 60% ETc (T3) and 40% ETc (T4) (Fig 8). Irrigation is provided by superficial drip micro-irrigation. Each elementary plot of water regime is divided into 4 sub-plots according to the nitrogen dose added (Fig 8). The plots fertilized by fertigation are of four combinations of nitrogen doses D1: 80, D2: 160, D3: 240 and D4: 320 kg N/ha. The fertilizer input was applied by fertigation (fertilizers are injected directly into the irrigation water).

Irrigation management
To ensure optimal irrigation of the crop, we carried out localized drip irrigation throughout the test campaign, taking into account precipitation and the water regimes to be tested. For this, an installation was created, where the ramps are spaced 40 cm apart on the same ramp door with integrated drippers with a nominal flow rate of 2 l/h and spacings of 40 cm.
The water regimes are defined based on coefficients that affect evapotranspiration in standard conditions (ETc) of sugar beet. The irrigation water comes from a storage basin and was brought by the network from the in situ well of the experimental area. The irrigation flow rate was measured by means of a meter downstream of the pump located at the pumping station, and then the water is conveyed to the plot by means of buried pipes. For each irrigation, a nominal flow rate of 2 l/h is set downstream of the pump. The irrigation water had good quality with an average electrical conductivity of 0.4 dS/m and a pH of 7.2. This electrical conductivity value did not present any restrictions for the use of water for localized irrigation (Ayers and Westcot, 1976). Drip irrigation is applied 2 to 3 times a week based on the accumulation of 2 or 3 days of evapotranspiration in standard conditions (ETc). To meet the water needs of the crop, 36 irrigations were applied from 10/28/2022 to 05/24/2022 one month before uprooting. For the first irrigation, significant quantities of water were applied, reaching 75.6 mm/h, the aim of which was to thoroughly moisten the soil over the entire surface 0-90 cm, to ensure germination and good seed emergence. Regarding the other following irrigations, they allowed compensation of water loss by evapotranspiration. To determine the irrigation duration of each water regime, the cumulative evapotranspiration was divided on the fictitious rainfall (6.17 mm/h). Tensiometers were installed in the space between the ramps and between the drippers at the experimental plot level to monitor soil moisture and water propagation in the soil horizons at the following depths: 30 cm, 60 cm and 90 cm.

Measuring irrigation frequency
Crop evapotranspiration (ETc) was assessed using the so-called climatic method, which indirectly estimates crop water requirements. Reference evapotranspiration (ET0), which represents the evaporative demand of the atmosphere at a given location and time, is estimated using the Penman-Monteith formula (1) (Allen et al., 1998).

$$\boldsymbol{ET_0} = \frac{\mathbf{0{,}408}\,\Delta\,(R_n - G) + \gamma \frac{900}{T+273} u_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0{,}34\,u_2)} \qquad (1)$$

With: - ET_0: Reference evapotranspiration [mm d^{-1}]; - Rn: Net radiation at the crop surface [MJ. m^{-2}. d^{-1}]; - G: Soil heat flux [MJ. m^{-2}.d^{-1}]; - T: Average daily air temperature at 2 m height [°C]; - - u_2 : Wind speed at 2 m height [m.s^{-1}]; - e_s : Saturation vapor pressure [kPa], $e_{a:}$ *Actual vapor pressure* [kPa]
The evapotranspiration of the crop under standard conditions ET_c is then calculated according to the formula (2):
In which *ETc* [mm], Kc: adjst the crop coefficient of sugar beet [-].

$$\boldsymbol{ETc = Kc.adjst * ET_o} \qquad (2)$$

The theoretical water deficit (DHT) by water regime is then calculated each day as follows (3):

$$\boldsymbol{DHT = ETc * Kr - Pe} \qquad (3)$$

With: - DHT [mm]; ET_c : Daily evapotranspiration of the crop [mm]; Pe: Effective rainfall [mm]= 0.8*P. P is the precipitation of the experimental site (mm). - Kr: The reduction coefficient which is specific to each treatment [-].1 (
The net irrigation dose (DNI) is calculated by the following relation (4) (Vermeiren and Jobling, 1983):

$$\mathbf{DNI = DHT * E * \frac{1}{CU} * Fw} \qquad (4)$$

With: - DNI [mm/d], - CU: is the irrigation uniformity coefficient measured at the installation level at the start of the campaign irrigation. - E: is the inverse of the irrigation yield (taken equal to 1.1). - Fw: is the proportion of the soil actually moistened.

The irrigation duration is calculated by formula (5):

$$\mathbf{T} = \frac{\mathbf{DHI}}{\mathbf{Pf}} \quad (5)$$

With: - T [h, min], - Pf: is the fictitious rainfall in [mm/h], given by the formula:

$$\mathbf{Pf} = \mathbf{n} * \mathbf{Q} \quad (\mathbf{6})$$

With: - n: is the number of drippers per m^2, -Q: is the average actual flow rate of the dripper measured at the start of the agricultural campaign (1.8 l/h).
The use of the formulas mentioned above results in the calculation of the irrigation duration in operation of the fertigation regime/water regime.

Fertigation modality

During the experimental year, the splitting of nitrogen inputs by fertigation was carried out based on the speed of nitrogen assimilation by sugar beet. Also, the fertilizing irrigations were split to avoid the risk of leaching by heavy rains. To do this, we divided the quantities planned for each level into one or two inputs per week from the six-leaf stage. The 40 kg N/ha of nitrogen were applied at sowing in the form of base fertilizer. The fertilizer used by fertigation for the nitrogen input was granulated ammonium nitrate NH_4NO_3 (33.5% N). The doses of granulated ammonium nitrate used are mainly D1: 80 kg N/ha, D2: 160 kg N/ha, D3: 240 kg N/ha and D4: 320 kg N/ha. We started to provide nitrogen doses from 04/12/2021 until 07/04/2022.

Morpho-physiological measurement of sugar beet

Every 15 days, samples of plant material were taken to measure morphological traits and analyze stomatal conductance. The number of samples taken is around 128 samples, with 8 samples for each nitrogen amendment regime (4) per water regime (4).
The samples were subjected to several measurements: the number of leaves (NF) linked to manual counting of the leaves, Root length (LR, cm): the measurement is done using a ruler, Leaf area (SF, cm^2): it is measured using a LIA-3100C planimeter, and stomatal conductance (CS, mmol. $m^{-2}.s^{-1}$): it was measured by the Leaf Porometer tool in order to study the diffusion of water between the leaf and the atmosphere via the stomata and the boundary layer.
To determine the rate of coverage of the green canopy in relation to the ground of the cultivated plots (TCC), we proceeded to take photos at the top of one meter of leaf bouquet during each period of the beet. The photos are processed by Acess software.

Measurement of soil moisture content by weight

To quantify soil water content (SWC), soil samples were collected using an auger at horizons 0-20, 20-40, 40-60, 60-80. For each nitrogen regime/water regime, 4 samples were collected. The samples collected are weighed in the wet state after putting them in the oven for 24 hours at a temperature of 105°C. The weight of the soil is considered once it is stable while considering the tare weight.
Soil water status (SWS) was measured in 6 depths: 100, 200, 300, 400, 600 and 1000 mm. Soil moisture (SWM) was collected 3 times a week using the gravimetric method with a capacitive probe such as the moisture meter HH2.

Measuring nitrogen supply at soil level

To monitor nitrogen mobility at soil level, samples were taken from the plots at different nitrogen doses applied per water regime. Three soil samples per plot at depths of 20 cm, 40 cm and 60 cm were taken for soil nitrogen analysis using the classical distillation method and Kjeldahl titration (Wan et al., 2021).
To determine root yield, an area of 8.1 m^2 was selected at each nitrogen regime/water regime plot to collect leaf and root biomass. Total root and leaf weights before and after drying to stabilization were measured using an electronic balance.

Statistical analysis

The results were analyzed by descriptive analysis, comparison of means and two-way ANOVA analysis.

Conclusion

In semi-arid regions, irrigation and fertilization management is essential to maximize agricultural yields, while preserving water resources. To ensure optimum physiological growth of sugar beet, it is essential to provide the necessary elements it needs but in a reasonable manner to ultimately achieve better root yields. Splitting nitrogen inputs limits high nitrogen concentrations in the soil solution and delays its migration to the depth. The 80% ETc water regime seems to offer a good compromise between reducing water consumption and maintaining acceptable root yield. The 80% ETc water regime could be coupled with fertigation with 160 kg N/ha of ammonium nitrogen. This value can serve as a basis for any strategy for developing beet fertilization in all beet production areas in arid and semi-arid climates where water resources are limited. However, further efforts are needed to optimize nitrogen management, to avoid nitrate leaching and ensure sustainable use of water and nutrient resources.

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Authors' Contribution

Conceptualization, B.B. and N.W.; methodology, N.T. and B.B.; software, N.T. and I.E.; validation, B.B. and N.W.; formal analysis, N.T. and Y.O.; investigation, N.T. and I.E.; resources, B.B. and N.T.; data curation, Y.O.; writing—original draft preparation, N.T.; writing-review and editing, N.T., I.E. and Y.O.; visualization, Y.O. supervision, B.B. and N.W.; funding acquisition, N.T. and B.B. All authors have read and agreed to the published version of the manuscript

References

Abyaneh H Z, Jovzi M, Albaji M (2017) Effect of regulated deficit irrigation, partial root drying and N-fertilizer levels on sugar beet crop (*Beta vulgaris* L.). Agric. Water Manag. 194: 13-23.

Allen R G, Pereira L S, Raes D, Smith M (1998) Crop Evapotranspiration (guidelines for computing crop water requirement).-FAO Irr Drain Paper N° 56, FAO, Rome.

Ayers R S, Westcot D W (1976) Water quality for agriculture. FAO Irr Drain Paper N° 29, FAO, Rome

Barbanti L, Monti A, Venturi G (2007) Nitrogen dynamics and fertilizer use efficiency in leaves of different ages of sugar beet (*Beta vulgaris* L.) at variable water regimes. Ann. Appl. Biol. 150 (2): 197–205..

Barzegari M, Sepaskhah A R, Hamid S (2017) Irrigation and nitrogen managements affect nitrogen leaching and root yield of sugar beet. Nutr. Cycl. Agroecosys. 108 : 211–230.

Bouazzama B (2000) Amélioration de l'efficience d'utilisation de l'eau chez les principales cultures fourragères au Tadla. Thèse de doctorat. Université de liège-Gembloux Agro-Bio Tech. Belgique. 243 p

Campbell R E, Viets F G (1967) Yield and sugar production by sugar beets as affected by leaf area variations induced by stand density and nitrogen fertilization. Agron J. 59: 349-354.

Cooke D A, Scott R K (1994) The Sugar Beet Crop: Science into Practice. Dordrecht, Springer.

Esmaeili A (2011) Evaluation of the effects of water stress and different levels of nitrogen on sugar beet (*Beta Vulgaris* L.). Sari Agricultural Sciences and Natural Resources University, Iran

Guo S L, Zhu H H, Dang T H, Wu J S, Liu W Z, Hao M D, Li Y, Syers J K (2012) Winter wheat grain yield associated with precipitation distribution under longterm nitrogen fertilization in the semiarid Loess Plateau in China. Geoderma. 189: 442–450.

Hongliang Z, Le W, Pengjie X, Dongfei L, Lijuan Z, Yuchen H, Kaiyong W, Hua F (2024) Nitrogen use efficiency of drip irrigated sugar beet as affected by sub-optimal levels of nitrogen and irrigation. Agric. Water Manag. 298: 378-390.

Li Y, Fan H, Su J, Fei C, Wang K, Tian X, Ma F (2019) Regulated deficit irrigation at special development stages increases sugar beet yield. Agron J. 111 (3): 1293–1303.

Ma L, Zhang X, Lei Q, Liu F (2021) Effects of drip irrigation nitrogen coupling on drymatter accumulation and yield of Summer Maize in arid areas of China. Field Crop.Res. 274: 108321.

Martin S S (1983) Sugar beet. In: Teare I.D., Peet M.M. (eds.): Crop-Water Relations. New York, John Wiley & Sons, 423-43.

Matthews L R (1986) The effect of water stress on the leaf area of *cucumis melo.* A thesis Submitted to the Graduate Faculty of Texas Tech University in Partial Fulfillment of theRequirements for the Degree of Master of Science, 70 p.

Moughli L (2019) L'irrigation localisée au Maroc : État des lieux et perspectives. Revue Marocaine des Sciences Agronomiques et Vétérinaires. 7(3), 15-22.

Ober E S, Bloa M L, Clark C J A, Keith A R, Jaggard W, Pidgeon J D (2005) Evaluation of physiological traits as indirect selection criteria for drought tolerance in sugar beet. Field Crops Res. 91(2-3) : 231-249.Quemada M, Gabriel J L (2016) Approaches for increasing nitrogen and water use efficiency simultaneously. Glob Food Secur-Agr. 9: 29–35.

Steduto P, Hsiao T.C., Fereres E., Raes D. (2012) Irrigation and Drainage Paper: Crop yield response to water. FAO, Rome.

Topak R, Süheri S, Acar B (2011) Effect of different drip irrigation regimes on sugar beet (*Beta vulgaris* L.) yield, quality and water use efficiency in middle Anatolian, Turkey. Irrig Sci. 2: 79–89.

Varga I, Jovi J, Rastija M, Kulundži A M, Zebec V, Loncaric V, Iljkic D, Antunovic M (2022) Efficiency and Management of Nitrogen Fertilization in Sugar Beet as Spring Crop: A Review. Nitrogen. 3: 170- 187.

Vermeiren L, Jobling G A (1983) Irrigation and Drainage Paper: Localised irrigation: Design, installation, operation, evaluation. FAO, Rome

Wan X, Wu W, Shah F (2021) Nitrogen fertilizer management for mitigating ammonia emission and increasing nitrogen use efficiencies by 15N stable isotopes in winter wheat. Sci Total Environ. 790: 147587.

Yuan G, Luo Y, Sun X, Tang D (2004) Evaluation of a crop water stress index for detecting water stress in winter wheat in the north China plain. Agric. Water Manag. . 64(1): 29-40.