

Water use efficiency in four irrigation regimes in bulb onion production in the Alto Chicamocha Irrigation District

Eficiencia en el uso del agua en cuatro láminas de riego sobre la producción de cebolla de bulbo para el Distrito de Riego Alto Chicamocha



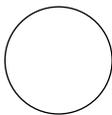
GERMÁN EDUARDO CELY-REYES^{1, 3}
KAREN VICTORIA SUÁREZ-PARRA¹
ROSALINA GONZÁLEZ-FORERO²

Bulb onion crop in the Usochicamoscha Irrigation District

Photo: K.V. Suárez-Parra

ABSTRACT

The bulb onion is one of the most important agricultural products in Colombia. The productive conditions of the Riego del Alto Chicamocha (Boyaca) district are a regional and national benchmark for this market. The objective of this research was to evaluate four irrigation regimes in terms of production and irrigation water efficiency in bulb onion crops. This trial was in the municipality of Nobsa, village of Dicho (Boyaca). A completely randomized design with four treatments was used: irrigation regime with 150% evapotranspiration (Evt); moisture-based irrigation regime, detected with soil moisture sensors; irrigation regime with 100% Evt; irrigation regime with 60% Evt, along with four repetitions. Starting three weeks after transplant and for 11 weeks (77 days), the polar diameter (cm), equatorial diameter (cm), root length (cm), leaf length (cm), SPAD units, stomatal conductance and irrigation water use efficiency were determined. The irrigation regime with 100% Evt had the best performance in terms of the polar and equatorial diameters and the root and leaf lengths, which were reflected in the fresh weight at harvest. The irrigation regime with soil moisture values obtained from remote sensors, with lower amounts of applied water, had better values for the transformation of water to fresh mass, with 13.64 kg mm⁻¹.



Additional key words: water; evapotranspiration; moisture sensors; irrigation water efficiency.

¹ Universidad Pedagógica y Tecnológica de Colombia, Grupo de Investigación GIPSO; Universidad de La Salle, Doctorado en AgroCiencias, Tunja (Colombia). ORCID Cely-Reyes, G.E.: 0000-0001-6312-3575; ORCID Suárez-Parra, K.V.: 0000-0003-2736-9070

² Universidad de La Salle, Facultad de Ingeniería, Bogota (Colombia). ORCID González-Forero, R.: 0000-0002-5860-657X

³ Corresponding author. german.cely@uptc.edu.co



RESUMEN

La cebolla de bulbo es uno de los productos agrícolas más importantes en Colombia; las condiciones productivas del distrito de Riego del Alto Chicamocha (Boyacá) son un referente regional y nacional para dicho mercado. El objetivo de esta investigación fue la evaluación de cuatro láminas de riego en términos de producción y eficiencia del agua de riego sobre la producción y eficiencia del agua para riego en el cultivo de cebolla de bulbo. El ensayo se ubicó en el municipio de Nobsa, vereda Dichó (Boyacá). Se empleó un diseño completamente al azar con cuatro tratamientos; lámina de riego al 150% de la evapotranspiración (Evt); lámina de riego basada en humedad detectada por sensores de humedad del suelo; lámina de riego al 100% de la Evt, y lámina de riego al 60% de la Evt con cuatro repeticiones. A partir de la tercera semana del trasplante, se inició el seguimiento por 11 semanas (77 días), se evaluó el diámetro polar (cm), diámetro ecuatorial (cm), longitud de raíz (cm), longitud de hojas (cm), unidades SPAD, conductancia estomática y eficiencia en el uso del agua de riego. La aplicación de la lámina de riego supliendo el 100% de la Evt mostró el mejor rendimiento en términos de diámetro tanto polar como ecuatorial, longitud de raíz y de hoja, los cuales se vieron reflejados en el peso fresco a cosecha. Las aplicaciones de láminas de agua basados en valores de humedad de suelo obtenidos a partir de sensores remotos, con menores cantidades de agua aplicada presenta mejores valores de transformación de agua en masa fresca con $13,64 \text{ kg mm}^{-1}$.

Palabras clave adicionales: agua; evapotranspiración; sensores de humedad; eficiencia de agua de riego.

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INTRODUCTION

The main objective of agriculture is to satisfy the food needs of humans, which is linked to the proper use of irrigation water, the main input for production (Gómez *et al.*, 2015). Agricultural production processes use 75% of available water, so proper use and conservation should be a priority, maintaining a productive and natural balance in hydrographic basins of high environmental interest (Ríos *et al.*, 2016). Because climate change has led to water scarcity, agricultural production has resorted to new production strategies and irrigation management, reducing the amount of water applied without affecting yield, which include the modernization of irrigation systems, intermittent irrigation programs and even the use of new varieties resistant to water stress (Sánchez *et al.*, 2017; Mai *et al.*, 2019).

Irrigation is a tool that improves productivity in agricultural systems, maintaining water in crops for maximum expression. The main concern in irrigation is when and how much water to use, which is determined with irrigation planning (Caicedo *et al.*, 2015). The use of water in irrigated agriculture depends on multiple factors in the soil, climate, management and environment; the efficient use of water is reflected in productivity (Bonet *et al.*, 2010; Wakchaure *et al.*, 2018).

Water productivity is a term coined by Kijne *et al.* (2003), a measurement in systems for the conversion of water to food, achieving efficiency when less water is applied and obtaining greater production (Ríos-Flores *et al.*, 2015). Current resource management practices use extensive modifications depending on the crop type that is irrigated (Bolaños *et al.*, 2017). The bulb onion requires frequent irrigation, is highly sensitive to water stress and generates high water losses because of inefficient and excessive irrigation (Channagoudra *et al.*, 2009; Haller and Jonsen, 2020).

Different methods are used to determine the amount of water to apply. Two reliable methods are evapotranspiration value management (Evt) and use of soil moisture sensors. Both methods require an evaluation of climate and edaphic factors, giving the calculation greater precision (Enciso *et al.*, 2009; Minhas *et al.*, 2020).

In Colombia, bulb onion production is distributed in various geographical areas of the country. The Department of Boyaca stands out as one of the main production areas, with more than 162,400 t, providing 54% of the total domestic production, and the upper Chicamocha irrigation district is a center of onion

cultivation, with a planted area that reaches 525 ha in each productive cycle. Therefore, the objective of this research was to analyze the physiological and productive development of bulb onions subjected to four irrigation regimes calculated with the climatic conditions (Evt) and soil moisture sensors in the Irrigation and Drainage District of Alto Chicamocha and Firavitoba- USOCHICAMOCHA Boyaca. Despite the adequate irrigation infrastructure, technical capacities have not yet been developed for the efficient use of water in agricultural production.

MATERIALS AND METHODS

This study was carried out from January to April, 2020 in a bulb onion crop (*Allium cepa* L.) established on the San Rafael Farm (5.787108°N, 72.973650°W; 2,593 m a.s.l.), in the village of Dicho, Nobsa municipality, Boyaca Department, within the Irrigation and Drainage district of Alto Chicamocha and Firavitoba-Usochicamocha. A completely randomized design with four treatments and four repetitions was used. This study had an experimental area of 600 m², divided into 16 plots of 37.5 m².

The irrigation regimes were: 1) 150% evapotranspiration (150% Evt, determined with the Making equation); 2) moisture-based irrigation regime, detected with soil moisture sensors (Vegetronix moisture sensors [VH400 model, Vegetronix, Riverton, UT] that evaluated the validity of the recorded data and measured the amount of water applied. This sensor was selected because it had the best performance according to the previous calibration process); 3) irrigation regime with 100% evapotranspiration (100% Evt), and 4) irrigation regime with 60% evapotranspiration (60% Evt).

A drip irrigation system was used, with self-compensated drippers, 1.0 L h⁻¹ discharge flow, and 20 cm between drippers. Each irrigation sector had an electronic regulation valve for the automated management of the irrigation times in each treatment. Two irrigation times per day were used: one in the morning with 50% of the total daily regime and the remaining 50% in the afternoon.

The physiological monitoring of the onion crop started with the installation of the irrigation system (week 3 of the transplant) and lasted until 77 d after transplant (11 weeks), including the variables: equatorial diameter (cm), polar diameter (cm), leaf length

(cm), stomatal conductance (SC-1 Leaf Porometer, Meter Group), and Relative Chlorophyll Index (CRI) or SPAD units (Soil Plant Analysis Development, Konica Minolta). At harvest, the total fresh weight for each treatment was determined.

The evapotranspiration (Evt) was determined with the equation proposed by Making. The climatic data for the Evt determination were obtained with a climatic station installed at the test site. Additionally, the irrigation water efficiency (IWUE) was determined using the formula proposed by (Kijne *et al.*, 2003) (1):

$$IWUE = \frac{Ya}{IW} \quad (1)$$

where *Ya* was crop yield in kg ha⁻¹, and *IW* was total amount of applied water (mm).

Finally, the values obtained with the physiological monitoring of the onions were processed in the free version of Infostat (Infostat, 2020), which used analysis of variance (ANOVA) and the Tukey multiple comparison analysis with a reliability of 95%.

RESULTS AND DISCUSSION

Table 1 shows the total supplied water (mm) for each treatment and the total onion production (kg ha⁻¹) and IWUE (kg mm⁻¹). The precipitation during the study was 212.10 mm, which aided establishment of the crop through direct dependence on water supplied through irrigation. Therefore, the precipitation value was not taken into account for the production analysis.

Table 1. Production values, total water supplied and irrigation water efficiency IWUE.

Treatment	Production (kg ha ⁻¹)	Total water (mm)	IWUE (kg mm ⁻¹)
150% Evt	46,130.92 c	11,574	3.98
Humidity sensor	53,819.41 b	3,943	13.64
100% Evt	64,583.3 a	7,716	8.37
60% Evt	34,308.3 d	4,630	7.41

Evt: evapotranspiration. Means with different letters indicate significant difference according to Tukey's test ($P \leq 0.05$).

The results in table 1 indicate that the treatment with the highest production was 100% Evt (64583.3 kg ha⁻¹), followed by the moisture sensors (with a

regime based on the moisture recorded by the sensors), 150% Evt, and finally 60% Evt, with the lowest production. When supplying 100% of the calculated Evt, higher production was obtained; however, water consumption was 51.1% greater than with the moisture sensors (3943 mm), with a regime calculated using moisture sensors, which had the best IWUE index: 13.64 kg mm^{-1} .

These results are contrary to those reported by Perez and Knox (2014), who observed higher IWUE efficiencies with reduced water applications because the availability of water during onion growth is not only determinant for bulb size but also influences storage time. A water restriction reduces yield and produces bulbs with a lower water content because of reduced expansion in the division of foliar cells, with delayed bulbification, leading to smaller diameters, lower weights, less volume and a larger breathable area. Smaller water regimes generate lower respiration rates and are positively correlated with physiological activity, which is generally higher than with greater regimes (Assuero *et al.*, 2007; Rattin *et al.*, 2011; Gerjes *et al.*, 2020; Liu *et al.*, 2020).

Physiologically, a water reduction negatively affects functions, such as photosynthesis, respiration, metabolic and anatomical reactions, growth, reproduction, absorption of mineral nutrients, transport of assimilates and production, by intervening in all biological processes. As a response to water stress, plants stop developing, with leaf wilting and a reduction in water potential, stomatal conductance, CO_2 assimilation and root hydraulic conductivity (Vélez *et al.*, 2012; Semida *et al.*, 2020).

The results from the water applications based on soil moisture agree with those reported by López *et al.* (2011), who argued that applications of irrigation regimes based on evapotranspiration and soil moisture generate greater water use efficiency, which is much greater when supplying up to 80% of the total water needs of the crop, achieving higher production with a reduced water volume and providing optimal cost-benefit ratios for large-scale irrigation systems (Gerjes *et al.*, 2020).

Growth of the polar diameter and equatorial diameter

The production and efficiency of the proposed system is better illustrated by the crop growth variables. Figure 1A shows growth in terms of the polar diameter, and figure 1B shows the equatorial diameter of the bulbs. For the polar diameter, significant statistical differences were found between the treatments with a 95% confidence level at weeks 2, 3, and 10. The growth of the polar diameter decreased from week 1 of the evaluation to week 8, with an increase in the equatorial diameter, especially when the plants entered the bulbous stage. On the other hand, from week 8 to week 11, there was new growth, accumulating the largest amount of photoassimilates, with increases in the polar and equatorial diameters (Estrada-Prado *et al.*, 2015).

The positive response in the polar and equatorial diameters in 100% Evt (Fig. 1A) was related to the applied water regime, which provided enough moisture in the soil for optimal cultivar production (Kumar *et*

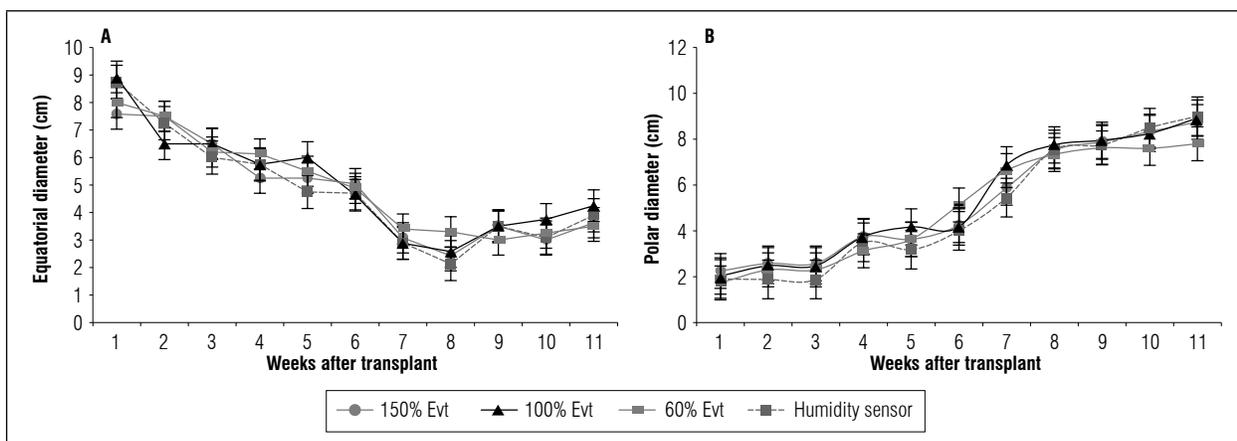


Figure 1. A, development of polar diameter in onion bulbs subjected to four irrigation regimes; B, development of equatorial diameter in onion bulbs subjected to four irrigation regimes. Evt: evapotranspiration.

al., 2007). In 60% Evt, which had a smaller polar diameter, the results agreed with de Santa (2004), who suggested that a reduction in a water regime decreases bulb growth because it is not possible to carry out the processes of cell division as fast as with the required amount of available water, generating water stress. This indicates that not only fertilization is required for bulb development; without adequate water in the soil, a plant will decrease in quality (Patel and Rajput, 2008; Dai *et al.*, 2020).

The results for the equatorial diameter had significant statistical differences ($P \leq 0.05$) in week 5. Moisture sensors and 100% Evt developed better, reaching average values of 8.92 and 9 cm, higher than those found by Cargua, (2013), who reported equatorial diameter values of 7.42 and 7.20 cm per bulb for the Yellow granex variety, lower even than the diameters of 7.8 cm in 60 % Evt.

Alvarez-Herrera *et al.* (2017) reported that the growth of bulb onions is sigmoidal, explaining the reduction of the polar diameter and increase of the equatorial diameter, with subsequent flattening related to the accumulation of photoassimilates during the bulbification stage. Kumar *et al.* (2007) stated that water regimes greater than the evapotranspiration normally generate an increase in the polar diameter of bulb onions, even when the applications reach 150% Evt. Additionally, stimulation of the soil temperature, which increases root length, will increase the availability of nutrients in solution for fulfillment of the basic metabolic processes, with a respective increase in the diameter and total weight of the plant (de Freitas *et al.*, 2020).

The results agreed with those found by Castro *et al.* (2009), who stated that, in the bulbification phase, the equatorial diameter increases up to 65% because of storage of photosynthesis products. The equatorial diameter value reported by these authors was 6.6 cm, close to the diameters found in 60% Evt, which, in both cases, were observed with water stress.

Leaf and root growth

Significant statistical differences were found with a $P \leq 0.005$ in evaluation weeks 2, 4, 7, and 8 for leaf length and in week 11 for root length. For leaf length (Fig. 2a), the value was almost constant from week 3 to 11, with the highest value in 100% Evt (60.5 cm). Treatments 150% Evt, moisture sensors and 60% Evt had lower values; 1 had the lowest value at 56.2 cm. The root length variable (Fig. 2B) had its highest value in 100% Evt, with a value of 14 cm. Treatments 150% Evt and moisture sensors had the lowest value at 12.5 cm.

The growth of the leaves and roots was closely related to the scarce water supply, as seen in 60% Evt, which triggered a reduction in plant growth. An adequate supply of water in regimes that provide 80 to 100% Evt can impart adequate root and leaf growth values (Shao *et al.*, 2008). Using smaller amounts of water, as with the moisture sensors, does not guarantee adequate root development, instead generating shorter and thicker roots and limiting the necessary amount of absorbed water because of a smaller surface area (Alvarez-Herrera *et al.* 2017; Wakchaure *et al.*, 2020).

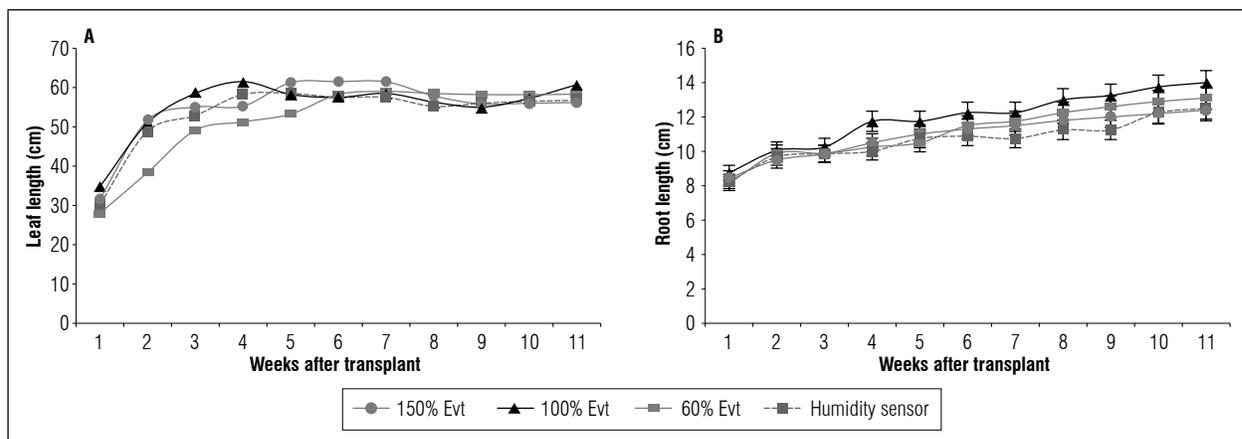


Figure 2. A, bulb onion leaf length under four irrigation regimes; B, bulb onion root length under four irrigation regimes. Evt: evapotranspiration.

The treatment 150% Evt had the shortest root length (8.13 cm) because, when the soil has moisture saturation, gases such as O₂ and CO₂ diffuse more slowly, making them inaccessible to the roots. As a result, the lack of oxygen decreases ATP production, causing a reduction in root metabolism and in plant nutrition (Sauter, 2013; Taiz *et al.*, 2015; Alvarez-Herrera *et al.*, 2017; Piri and Naserin, 2020).

The treatment 150% Evt also had the lowest leaf length value because the high moisture saturation in the soil decreased the oxygen and caused anoxia in the soil, producing a greater amount of aminocyclopropane carboxylic acid (ACC) that was transported from the roots to the aerial part, where it becomes ethylene, decreasing growth and foliar abscission (Irfan *et al.*, 2010; Steen and Benkeblia, 2013; Sarkar *et al.*, 2019).

Relative chlorophyll index (RCI) or SPAD units

In the first weeks after transplant, all treatments had a similar trend until week 4. In week 5, there was a high RCI value. The higher values were seen with the moisture sensors and 60% Evt, 140.55 and 132.9, respectively. The treatments 150% Evt and 100% Evt presented lower values, 103 and 108.13, respectively. The values decreased again in week 6, increased in week 7, decreased in week 9, and increased again until week 11, when the harvest occurred. The treatments moisture sensor and 60% Evt presented higher values, followed by 150% Evt and 100% Evt, which presented a similar value (107). There were only significant differences in weeks 3,

4, and 5 according to Tukey's multiple comparison test ($P \leq 0.05$) (Fig. 3).

In the first four weeks, the SPAD readings remained almost constant. In week 5, there was considerable growth, which could have been due to targeting photoassimilates (Bonza-Espinoza *et al.*, 2016). Sampling point 5 had the highest SPAD unit peak, related to the physiological reaction of the plants to the application of amino acids (AAS), supplied to counteract the effects of low temperatures in that week, which provided significant amounts of N necessary for the synthesis of chlorophyll. The high concentration of foliar nitrogen in the plants, which is directly reflected to SPAD unit values, meant a higher value, especially in treatments that had lower amounts of water (Castillo and Ligarreto, 2010).

The chlorophyll results agreed with those obtained by (Palencia *et al.*, 2016), especially in the later weeks of the analysis, where the SPAD units measured in old leaves had similar values, in the range of 60 and 80 s. The significant increase in the later weeks was evidence of the fertilization response of bulb filling, which was carried out in week 9, with the physiological response detected in weeks 10 and 11 (Arjona *et al.*, 2004; Medellín *et al.*, 2011).

Stomatal conductance

There were significant statistical differences with $P \leq 0.05$ at sampling points 5, 9, and 11 (Fig. 4).

Figure 4 shows the stomatal conductance, which increased and decreased over time in relation to

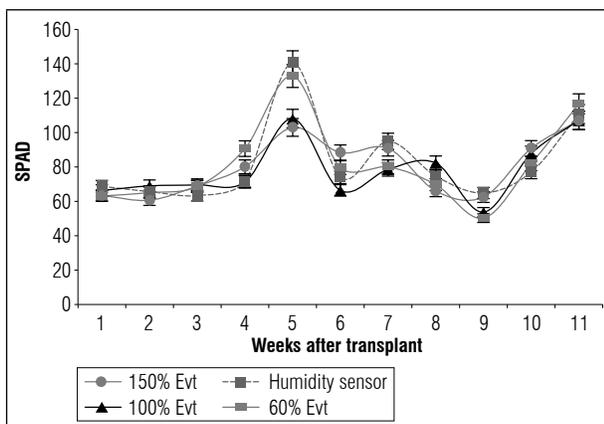


Figure 3. SPAD units in bulb onions under four irrigation regimes. Evt: evapotranspiration.

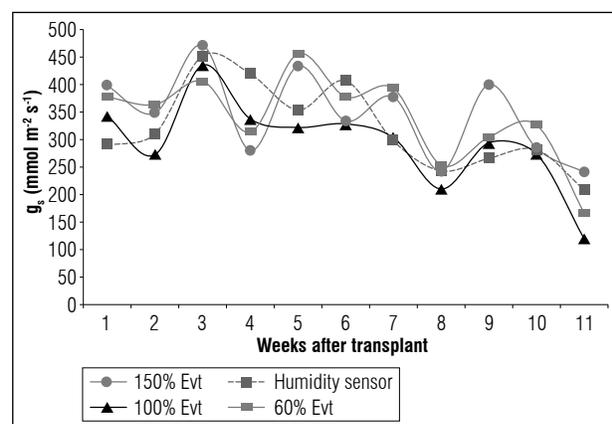


Figure 4. Stomatal conductance in bulb onions under four irrigation regimes. Evt: evapotranspiration.

variations in the sodium concentrations in the soil because of the crop field salinity, especially on days where high temperatures resulted in dehydration of the first centimeters of the soil. Soil salinity generates stress in roots because of the synthesis of abscisic acid (ABA) as an early response to physiological changes, such as the reduction of hydraulic conductivity and remote stomatal closure, generating direct blockage in photosynthesis because of the limited entry of CO₂, a necessary substrate for the Calvin cycle (Jiménez *et al.*, 2012; Quintana *et al.*, 2016).

Coca *et al.* (2012) stated that sensitivity to saline stress in onions varies directly with the phenological stage and may be associated with other pathologies, which may include the conditions that lead to increased pink root incidence, directly affecting root growth, root thickness, and production, with a reduction in water potential, preventing the absorption of water by roots, and cellular reduction of the root apex and young leaves. This is more evident in root length because of a reduction in the capacity to uptake nutrients such as K⁺ and Ca⁺² (Semida *et al.*, 2020).

The use of porometers or other devices for measuring stomatal conductance and water potential in onion bulbs is limited because anatomical structures on leaves are covered by a waxy layer or cuticle, stomata are sunken and guard cells lack starch and chloroplasts. The concentration of atmospheric CO₂ and light intensity directly influence stomatal opening; the radiation that occurs in the Tundama Valley region contributes to above normal values. The use of measurement instruments may be limited, and values may be biased (Perez and Knox, 2014; Semida *et al.*, 2020).

CONCLUSIONS

Determining the irrigation regime with the soil moisture sensors led to the use of a smaller amount of water and to a higher water yield in terms of IWUE, as compared to the irrigation regimes calculated with the Evt.

The 100% Evt regime saw the highest bulb onion production value.

Monitoring the relative chlorophyll index or SPAD units and stomatal conductance indicated that the irrigation regimes did not result in significant

differences because of the influence of different physiological and climatic variables that directly affect the validity of data recorded by devices.

Expand studies on the edaphoclimatic variables of the study area are needed to provide technical measures for the efficient use of irrigation water.

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Conflict of interests: The manuscript was prepared and reviewed with the participation of the authors, who declare that there exists no conflict of interest that puts at risk the validity of the presented results.

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