Determination of an efficient irrigation schedule for the cultivation of rose cv. Freedom under greenhouse conditions in Colombia

Determinación de una programación de riego eficiente para el cultivo de la rosa cv. Freedom bajo condiciones de invernadero en Colombia

Jhon Jairo Arévalo[1], Javier Enrique Vélez S.[2], and Diego Sebastiano Intrigliolo[3]

ABSTRACT

An experiment on rose (*Rosa* sp.) cv. Freedom was performed in a greenhouse on the Bogota Plateau, Colombia, to identify an efficient irrigation regime for this crop. The tested treatments were based on three irrigation doses, applying different fractions of the estimated crop evapotranspiration (ETc), calculated using a class A evaporation tank: i) 100% ETc (ETc100), ii) 80% ETc (ETc80) and iii) 70% ETc (ETc70). During the entire experimental period, from mid-May to early September, the crop had a constant production of floral stems. In all of the irrigation treatments, the soil and plant water status were monitored using tensiometers and the midday stem water potential, respectively (Ψstem). In the fully irrigated roses, the actual water use was determined using a drainage lysimeter in order to obtain the local crop coefficients (Kc) by means of a water balance. From June to August, the obtained monthly Kc values varied between 1.10 and 1.26. Compared to the ETc100 treatment, 14.5 and 21.8% less water was applied in treatments ETc80 and ETc70, respectively. Despite this fact, no statistically significant differences were found among the treatments for rose production or quality. Finally, in the more irrigated roses, tight relationships between the stem water potential and vapor pressure deficit were obtained. The reported base-line equations can be used for predicting the optimum rose plant water status, depending on the environmental conditions. Overall, the reported results can be used for an efficient irritation schedule for rose crops under greenhouse conditions, using the local Kc and direct determinations of plant water status corrected for the evaporative demand.

Key words: evapotranspiration, soil moisture, leaf water potential, ornamental plants.

RESUMEN

Se realizó un experimento en un cultivo de rosa (*Rosa* sp.) cv. Freedom, bajo invernadero en la Sabana de Bogotá, Colombia, con el fin de identificar el régimen de riego más adecuado. Los tratamientos se basan en tres dosis de riego aplicando diferentes fracciones de la evapotranspiración del cultivo (ETc) estimada, calculada utilizando un tanque de evaporación clase A: i) 100% ETc (ETc100), ii) 80% ETc (ETc80) y iii) el 70% ETc (ETc70). Durante todo el período experimental, a partir de mediados de mayo y hasta principios de septiembre, el cultivo tuvo una producción constante de los tallos florales. En todos los tratamientos de riego, el suelo y el estado hídrico de la planta fueron monitoreados usando tensiómetros y el potencial hídrico del tallo respectivamente (Ψtallo). En el tratamiento ETc100, el consumo de agua se determinó usando un lisímetro de drenaje con el fin de obtener coeficientes de cultivo locales (Kc) por medio de un balance de agua. Durante junio a agosto, los valores de Kc mensuales obtenidos variaron entre 1,10 y 1,26. En comparación con el tratamiento ETc100, se aplicó 14,5 y 21,8% menos de agua en los tratamientos ETc80 y ETc70, respectivamente, sin presentar diferencias significativas entre los tratamientos en producción, calidad y color de la rosa. Por último, en las plantas más irrigadas, se obtuvo una estrecha relación entre el potencial hídrico del tallo y el déficit de presión de vapor. Las ecuaciones encontradas se pueden utilizar para predecir el estado óptimo del agua de la planta, dependiendo de las condiciones ambientales. En general, los resultados reportados se pueden utilizar para una programación de riego eficiente del cultivo de rosa bajo condiciones de invernadero, utilizando los Kc locales y la determinación directa del estado hídrico de la planta corregida por la demanda de evaporación.

Palabras clave: evapotranspiración, humedad del suelo, potencial hídrico de la hoja, plantas ornamentales.

Introduction

Colombia is the world's second-largest exporter of fresh-cut flowers, accounting for 14% of worldwide exports in 2009, after The Netherlands' share of 47% (Montero and Franco, 2009). In addition, Colombia is the leading provider of imported flowers in the United States, accounting for 60% of imports, and ranks fourth in the European Union with 4% of imports (Asocolflores, 2009). In Colombia, floriculture is the first line of non-traditional agricultural

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[1] Jefe Mirfe, The Elite Flower SAS. Facatativa (Colombia).
[2] Faculty of Engineering, Universidad Nacional de Colombia. Bogota (Colombia). jevelezs@unal.edu.co
[3] Department of Natural Resources, Instituto Valenciano de Investigaciones Agrarias (IVIA). Valencia (Spain).

exports, generating approximately 15 jobs per hectare and more than 180,000 formal jobs connected to direct and indirect production (Montero and Franco, 2009). The major producing areas of roses in Colombia are the Bogota Plateau, Antioquia and the central/west region, accounting for 76, 19 and 5% of national production, respectively (Asocolflores, 2009). Greenhouse cultivation of roses in soil is the most commonly used system throughout the Bogota Plateau, followed by soilless crop cultivation using burnt rice husk, coconut fiber and mixtures, among other materials (Quintero, 2009).

Irrigation scheduling is generally based on estimating plant water needs using a model that takes into account the weather conditions and crop characteristics (Allen *et al.*, 1998). As a result, crop evapotranspiration (ETc) is derived from the reference evapotranspiration (ETo) times the crop coefficient (Kc). This empirical approach does not fully take into account the many crop and environmental factors that might affect Kc (Annandale and Stockle, 1994). For instance, Katsoulas *et al.* (2006) demonstrated that, contrary to other crops, rose production is constant and, therefore, the transpiration area is highly variable; this effect is a significant factor when formulating an irrigation schedule model. Other relevant variables that potentially affect Kc values include: complementary illumination systems, heating pipes, relative humidity modification and CO_2 concentrations within greenhouses (Raviv and Blom, 2001). Alternative procedures to the Allen *et al.* (1998) approach for efficient irrigation scheduling could be adopted.

A complete analysis of the soil-plant-climate continuum can be used when attempting to estimate on-site plant water needs. The leaf water potential is proportional to the soil water potential gradient and inversely proportional to the resistance developed by the soil, plants and the atmosphere (Raviv and Blom, 2001). An initial potential flow measure based on the soil matric potential (Ψs) at the root zone allows for the determination of plant soil water availability. Therefore, monitoring soil moisture can be used for decision-making in irrigation scheduling, assessing the amount and frequency of water applications, avoiding deep percolation losses and runoff, reducing energy use and assessing fertilizer movement below the root zone (Enciso *et al.*, 2007; Bonet *et al.*, 2010). Subsequent measurements of plant water status using a pressure chamber should also be used to assess the adequacy of the imposed irrigation regime and to determine the severity of plant water stress when deficit irrigation is employed. The leaf water potential can be measured either at pre-dawn or at mid-day (Intrigliolo and Castel, 2006). Nowadays, the midday stem water potential (Ψstem) is more often employed because it allows for determining the plant water status under a given soil water status and environmental conditions (Naor, 2006). The Ψstem also has the advantage over leaf water potential measurements of having a lower leaf-to-leaf variability (Shackel *et al.*, 1997). However, the coupling of the plant with the evaporative demand makes its water status dynamic in response to several fluctuating environmental properties (Reicosky *et al.*, 1975; Hincley and Bruckerhoff, 1975). This means that a single measurement of plant water status may be meaningless if taken without a reference value from plants without soil water limitations. Therefore, empirical equations relating the day-to-day variation in the water status of well watered plants to the changing environmental conditions should be derived.

Deficit irrigation can be also used as a measurement for increasing water use efficiency. However, plant water stress has a negative effect on the photosynthetic rate, stomatal conductance, leaf water potential and relative water content and leads to a decrease in leaf chlorophyll, the transpiration rate and the production of floral stems (Bolla *et al.*, 2010). Chimonidou-Pavlidou (1999) reported that severe drought stress is harmful for rose plant development, decreasing production by up to 70%, affecting rose quality and reducing stem length and fresh weight. On the other hand, Caballero *et al.* (1996) found that drought stress during leaf area development does not affect the stem quality, although production is delayed by 10 to 15 d. Based on these prior results, rose plants can be considered sensitive to severe deficit irrigation, but the effects of mild water restrictions under low evaporative demand conditions, such as on the Bogota, Plateau have not been well investigated. Under a low evaporative demand, plants with mild water restrictions are still able to transpire at a rate close to that of well-watered plants (Van den Honert, 1948; Denmead and Shaw, 1962), implying that plant responses to soil water limitations might be dependent on the evaporative demand.

The global objective of this study was to determine an efficient irrigation scheduling strategy for the rose cv. Freedom crop under greenhouse conditions in Colombia. Actual rose water use and responses to different irrigation doses are reported.

Materials and methods

Experimental plot and irrigation treatments

This study was carried out between March and September of 2011 on the Bogota Plateau (Facatativa, Cundinamarca). The study area has an average temperature of 14°C, the reference crop evapotranspiration is 667 mm year^{-1} according to the Thornthwaite method, the average relative humidity is 50%, the average daily solar brightness is 4.3 h and the average annual precipitation is 651 mm year^{-1}. The study was performed on the geographic coordinates of 4°46'38.35" N, 74°19'38.15" W at 2,614 m a.s.l. In the greenhouse, 116.8 x 54.0 m containers with 10 beds per container were used for a total of 110 beds; each plot was 23.5 m in length and 1.0 m in width with a 0.5 m path.

The studied crop was rose (*Rosa* sp.) cv. Freedom, which is a hybrid tea type of rose. The roses were planted in May 2006. Each bed had one row and the plants were separated by 0.1 m for a total of 235 plants/bed. The production system was continuous and all phenological stages were represented. The typical local soil is sandy loam, 0.60 m in depth, with a very high organic matter content because every year 480 kg/bed of compost applications are added to the soil, including rice hulls and manure. The soil average bulk density, field capacity (FC) and permanent wilting point (PWP) are 0.80 t m^{-3} and volume water content of 55.1 and 45.4%, respectively. The FC and PWP were obtained by the pressure plate technique (Richards and Fireman, 1943). The irrigation water, obtained from the Botello river and stored in a reservoir; had a pH of 7.9 and an electrical conductivity (EC) of 0.48 dS m^{-1}.

The experimental design consisted of completely randomized parcels with homogeneous units. Three treatments with three replicates per treatment were performed. Nine plots of 10 beds were selected. Experimental data were collected in two central beds per plot.

The treatments throughout the trial consisted of three irrigation regimes corresponding to: i) 100% (ETc100), ii) 80% (ETc80) and iii) 70% (ETc70) of the estimated crop evapotranspiration (ETc) as a starting point for these crops, because there is no reference for our conditions. The crop evapotranspiration (ETc) was calculated as the product of the reference crop evapotranspiration (ETo), which was estimated based on a class A tank evaporation system installed inside the greenhouse and the crop coefficient (Kc). ETo is defined as the product of the water evaporation based on the class A tank evaporation (Etan) and the tank coefficient (Ktan), which is calculated using the relative humidity conditions, temperature, air speed and location within the greenhouse, as reported by Allen *et al.* (1998). The crop coefficient (Kc) used was 1.15.

The irrigation was carried out when the soil matric water potential (Ψs) reached -18 and -20 kPa. The applied water volume was controlled by varying the time duration of the irrigation applications, maintaining the same frequency across the treatments. The cultivation practices were identical for all of the treatments. Fertilizer applications, which were performed weekly using the irrigation system, had pH values between 5.5 and 6.5, CE values from 0.8 to 1.5 dS m^{-1} and nitrate NO_3 concentrations between 100 and 120 mg kg^{-1}.

Measurements of the soil and plant water potential

The soil water potential was measured daily at 7:00 AM using nine Irrometer® tensiometers (Irrometer Company, Inc., Riverside, CA) per treatment at a 0.40 m depth, *i.e.*, the level where the greatest percentage of active roots is found, and at 10 cm from the emitter and 5 cm from the drip line. The obtained values were compared with the values from the soil moisture retention curve (Fig. 1) to continuously determine the moisture throughout the trial. tensiometers-nine tensiometer were used per treatment.

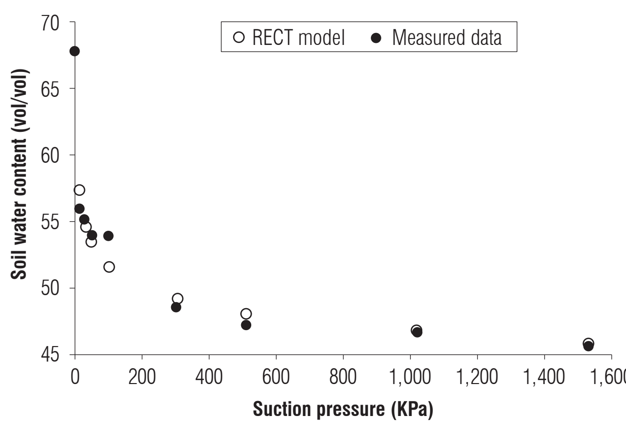

FIGURE 1. Soil water retention curve for the 0.4 m soil depth in a sandy loam soil for greenhouse rose production in Colombia. Measured and RETC model simulation data are depicted. Data shown are average values of nine samples.

The leaf water potential (Ψstem) was measured using a Model 600® Pressure Chamber Instrument (PMS Instrument Company, Albany, OR). Measurements were taken every week, 4 d after irrigation, between 12:00 and 14:00 HR. Four leaves from the middle third of two plants per plot were sampled for a total of 24 leaves per treatment. The leaves were sealed in polyethylene bags and covered with foil 1 h prior to the measurement to equilibrate the sample with the environment. The air vapor pressure deficit (VPD) was calculated based on the temperature and relative humidity measurements, determined using a hygrometer located inside the greenhouse. Solar radiation information was obtained from a meteorological station located near the farm.

Measurement of plant water use and local crop coefficients

The actual crop water use was determined using a volume lysimeter located in the ETc100 treatment. Measurements started at week 20 (mid May) and continued until week 36 (mid September). The test plot was 1.2 x 0.8 x 1.6 m with 12 drippers in an approximate area of 0.96 m^2. The drained volume was measured after 48 h of irrigation to determine the water balance, which is the difference between the amount of irrigated water and the volume of lysimeter drainage water ± changes in the soil moisture content (Eq. 1),

$$W.b. = (ET_{c\ lysimeter}) = I - LD \pm \Delta moisture \qquad (1)$$

where,

W.b. = water balance (mm)

I = irrigation (mm)

LD = lysimeter drainage [drain (mm)]

Δmoisture = soil moisture variation between irrigation events

The crop coefficient (Kc) was determined as the relationship between the lysimeter evapotranspiration and reference evapotranspiration values (Eq. 2),

$$\text{Kc} = \frac{ETc_{lysimeter}}{ETo} \qquad (2)$$

where,

K_c = crop coefficient

Etc $_{lysimeter}$ = lysimeter crop evapotranspiration (mm)

ETo = reference evapotranspiration estimated based on a class A tank (mm)

Floral stem production measurements were taken every week for two beds per treatment and were repeated for a total of 18 beds, six per treatment, from week 18 (May 1st) to week 36 (September 9th). The harvested stem quality was determined by measuring the final length and diameter in 12 units per plot.

Statistical analysis

Statistical analysis of the data was performed using the IBM® SPSS® 18 statistics software. The results were analyzed using ANOVA and Duncan's multiple range tests at a level of significance of $P \leq 0.05$.

Results and discussion

Environmental conditions and irrigation applications

The average monthly environmental conditions in the greenhouse between May and September of 2011 show that August was the driest month, with high VPD and temperature values and low relative humidity, which is in agreement with the highest observed ETo and crop evapotranspiration measured in the lysimeter ETc. (Tab. 1).

The total amount of irrigation applied in the ETc100, ETc80 and ETc70 treatments were 8.75, 7.48 and 6.84 m^3/bed, respectively. These values are equivalent to 2.383, 2.037 and 1.867 m^3 ha^{-1}, respectively. The water savings obtained in treatments ETc80 and ETc70, compared to the ETc100, were equivalent to 14.6 and 21.8%, respectively. The seasonal variations of weekly values of the irrigation applications and actual crop evapotranspiration values measured using the lysimeter are shown in Fig. 2A and 2B.

At the beginning of the experiment (weeks 16 and 17), when irrigation was applied to all the treatments according to the grower criteria, around 22 mm $week^{-1}$ were applied. In week 19, irrigation started to be applied differentially to the treatments, scheduled according to the estimated ETc and the water application in the ETc100 treatment decreased to around 22 mm $week^{-1}$ (28% less water than what the grower was previously applying) (Fig. 2). This result suggests that, when exclusively following more scientific criteria for scheduling irrigation (*i.e.,* estimating ETc, using ETo and

TABLE 1. Monthly average values of midday air vapor pressure deficit (VPD), average relative air humidity from 06:00 to 18:00 HR and air temperature. Crop evapotranspiration measured in the lysimeter (ETc). Reference evapotranspiration (ETo) based on the class A tank evaporation and average measured crop coefficient (Kc = ETc/ETo) are also shown.

Parameter	May	June	July	August	September
VPD (kPa)	4.1	4.4	3.2	5.0	3.8
Relative humidity (%)	70.4	62.7	64.7	59.0	62.9
Average temperature (°C)	18.0	19.4	18.2	19.8	18.2
Minimum temperature (°C)	7.3	4.9	5.3	4.4	4.1
Maximum temperature (°C)	33.6	36.2	29.9	37.1	32.4
ETo (mm $month^{-1}$)	17.3	28.0	21.9	30.9	6.8
ETc (mm $month^{-1}$)	19.9	30.8	27.5	34.7	7.8
Kc (ETc/ETo)		1.10	1.26	1.12	

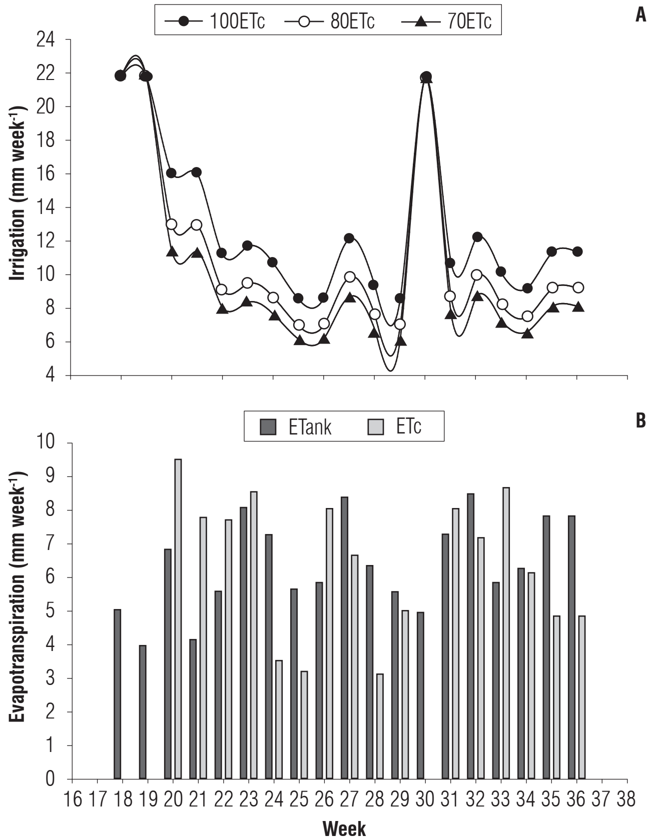

FIGURE 2. Sesonal variations of the weekly values of irrigation amounts applied to each treatment (A), actual crop evapotranspiration measured in lysimeter (ETc) and the Reference evapotranspiration based on the class A tank evaporation (ETank) (B). Treatments were irrigated at either 100, 80, or 70% of the estimated crop evapotranspiration (ETc).

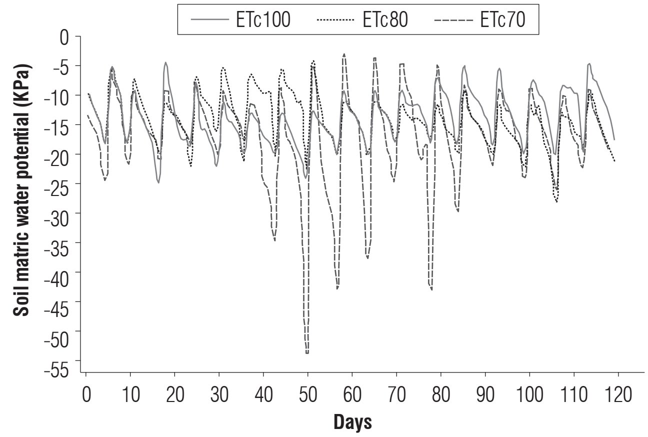

FIGURE 3. Seasonal variation of the soil matric water potential (Ys) in the different treatments irrigated at either 100, 80%, or 70% of the estimated crop evapotranspiration (ETc). Data shown are an average of nine tensiometers per treatment.

fixed Kc value of 1.15), a significant amount of water was saved with respect to the standard grower practice. It should be noted that, in week 30, due to a failure in the irrigation system, 22 mm week^{-1} were applied in all the treatments.

Soil matric potential

The soil matric potential (Ψs) was measured for 119 d, from week 18 to 36, with minimum and maximum values observed between irrigations of -6 to -24 kPa in ETc100, -8 and -24 kPa for ETc80 and -8 and -54 kPa for ETc70 (Fig. 3). In the ETc70 treatment, the most negative value, -54 kPa, was registered in July, corresponding to a relative volumetric water content of 54%, below the FC (55.1%). In other trials, Plaut *et al.* (1973) reported maximum floral stem production in sandy loam soils when Ψs was between -5.0 and -20 kPa and production decreased when Ψs was between -21 to -50 kPa in rose cv. Baccara. Raviv and Blom (2001) reported that the matric potential values should be maintained near -1 to -10 kPa for optimum rose production in substrate.

Midday stem water potential

As shown in Fig. 4, the seasonal variation of Ψstem varied with the imposition of the three irrigation levels and the environmental conditions, namely VPD.

In general, for all the treatments, the Ψstem values fluctuated between -0.23 and -0.71 MPa. These values are indicative of a near-optimum water status. In fact, Ψstem values reported here are less negative than the values of -1.00 and -0.90 MPa reported by Lio and Cohen (2005) for rose cultivar Sonia grown in substrate as well as the values of -1.59 and -1.28 MPa reported by Urban and Langelez (2003) for rose cultivars First Red and Twingo, respectively. Van Doorn and Vojinovic (2002) reported vase petal abscission problems for rose cultivars Sonia, Frisco and Cara mia when the leaf water potential reached values lower than -2.0 MPa, which is well below the values observed in this experiment.

In the present experiment, the ETc80 treatment had the lowest Ψstem, -0.71 MPa, at week 31, coinciding with the highest temperature (36.3°C), radiation (3.62 MJ m^{-2}), VPD (3.75 KPa), and ETc (7.24 mm week^{-1}) values as well as the lowest relative humidity (41.6%). The ETc100 treatment had the highest Ψstem values, -0.23 MPa, at week 35.

The day-to-day variation for the Ψstem of the ETc100 treatment was related to the solar radiation and air VPD (Fig. 5). On the other hand, the daily variations in VPD explained 72% of the variation found in the recorded daily Ψstem values. The relationship between Ψstem and solar radiation was not statistically significant at $P \leq 0.05$. Similarly to the present results, Urban and Langelez (2003) also found

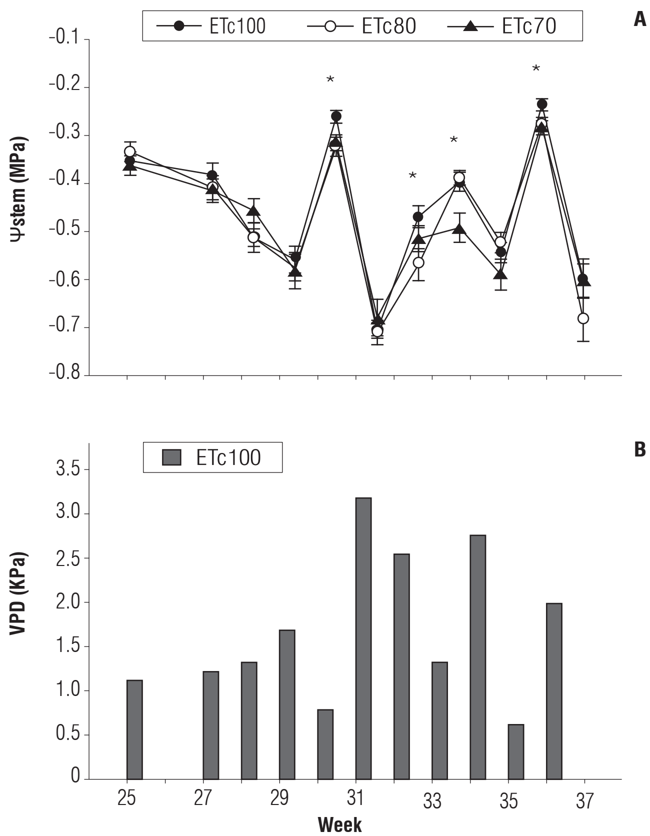

FIGURE 4. Seasonal variation of A, the midday stem water potential (Ψstem) measured in the different treatments irrigated at either 100, 80 or 70% of the estimated crop evapotranspiration (ETc). B, the midday air vapor pressure deficit (VPD) when the Ψstem measurements were taken. Ψstem values shown are the average of 24 determinations per treatment. Error bars indicate standard error of measurements. * Indicates significant differences among treatments relative to the control according to the Duncan´s test ($P \leq 0.05$).

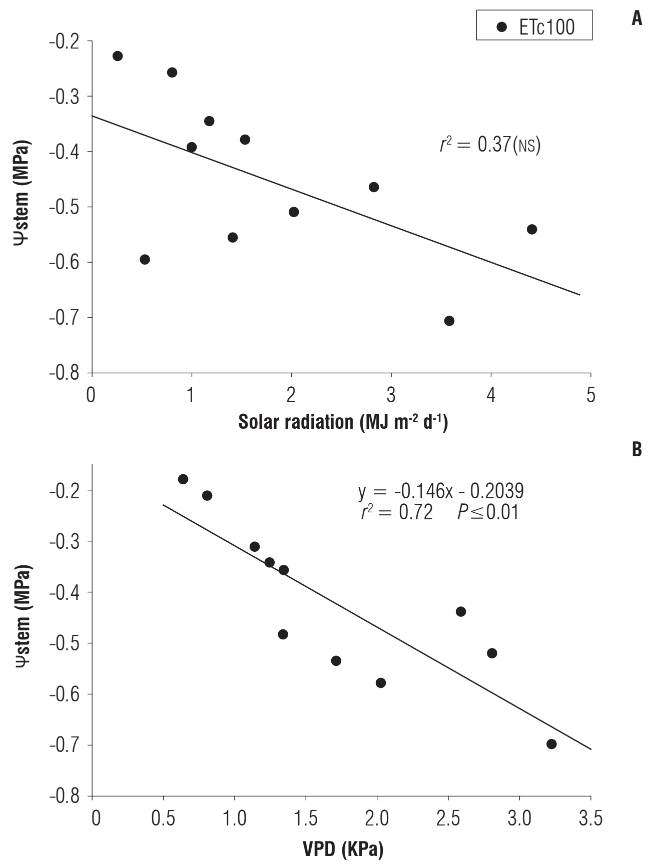

FIGURE 5. Relationships between the midday stem water potential (Ψstem) and A, the Solar radiation and B, vapor pressure deficit in the Etc100 treatment. The Ψstem values shown are an average of 24 determinations obtained in the treatment irrigated at 100% of the estimated crop evapotranspiration. NS = not significantly different.

tighter relationships when Ψstem was correlated with VPD than with solar radiation.

The linear equations reported in Fig. 5. help to indicate the optimal moment for the application of irrigation before registering Ψstem values, which limits crop production. Because temporal variations in Ψstem are dependent on the evaporation demand in addition to irrigation, by measuring temperature and relative humidity inside the greenhouse, it is possible to use the obtained equations to predict the Ψstem value for well-irrigated roses.

Evapotranspiration and crop coefficient (Kc)

During the experimental period, the measured crop evapotranspiration varied greatly, reaching values as high as 9 mm week^{-1} and as low as 3 mm week^{-1} (Fig. 2). During the same period, the crop coefficient varied (Kc) from 0.58 to 1.78 (results not shown), with a mean of 1.13 and a coefficient of variation (CV) of 35.9%. It is possible that this wide range is due to the constant variation of the transpiring area, resulting from the daily harvest of floral stems. However, from June to August, the Kc variations were small and the monthly average values varied only from 1.10, recorded in June, to 1.26, obtained in July (Tab. 1).

Floral stem production

No statistically significant differences ($P \leq 0.05$) in the total floral stem production were observed among the treatments, with 8,531, 8,094 and 7,863 units for ETc100, ETc80 and ETc70, respectively. The average productivity for ETc100, ETc80 and ETc70 was 1.32, 1.28 and 1.24 stems/plant per month. In addition, the proportion of stem diameter, either lower or higher than 7 mm, was similar in all treatments (Tab. 2).

Despite this, there was a trend in the most irrigated treatment (ETc100) to have stem length proportions higher than 80 cm; the reported numerical differences were not statistically significant at $P \leq 0.05$ (Tab. 2). Overall, these results suggest that increasing water applications over 70% of the estimated crop evapotranspiration does not result in a positive impact in terms of both floral stem production rates and individual stem vigor. In addition, no significant differences among the treatments could be detected in the rose shelf life (results not shown). These results could be explained by considering that the plant water stress developed by the less irrigated treatments were minimal when compared to the control plots.

TABLE 2. Floral stem length and diameter in two different classes. Values shown are average treatment values. Treatments were irrigated at either 100, 80, or 70% of the estimated crop evapotranspiration (ETc). Differences among treatments were not statistically different at $P \leq 0.05$.

Treatment	Stem diameter (%)		Stem length (5)	
	≤ 7 mm	≥ 8 mm	≤ 80 cm	≥ 90 cm
ETc100	61	39	62	38
ETc80	62	38	69	31
ETc70	62	38	69	31

Conclusions

This study can be considered a first approach for a more efficient irrigation scheduling procedure for rose cv. Freedom under greenhouse conditions in Colombia. On one hand, specific crop coefficients were obtained that varied between 0.71 and 1.26, suggesting high water needs for rose plants. On the other hand, reference, base-line equations relating day-to-day variations in the Ψstem with the evaporative demand were obtained, allowing for the prediction of optimum rose plant water status depending on the environmental conditions. These equations can be used by rose growers for determining if the irrigation schedule is mantaining the plants under optimum water status. Finally, considering that the imposed treatments did not affect the yield or quality of the roses, the optimum irrigation regime was quantified as 70% of the estimated crop evapotranspiration. For future research, the application of controlled deficit irrigation, *i.e.*, at less than ETc70, is recommended to determine the minimal irrigation level that does not affect the exportable floral stem quality and production.

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