ORIGINAL ARTICLE

Considerations on the Use of Simplifications in the Agronomic Design of Localised Irrigation Systems

Consideraciones sobre el uso de simplificaciones en el diseño agronómico de sistemas de riego localizado

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ABSTRACT: During the agronomic design of micro-sprinkling systems, it is difficult to guarantee the wetting of a volume of roots that allows the appropriate extraction of water and nutrients, as well as adequate anchorage. This leads to extreme precision at this stage, essentially in the estimation of crop coefficients K_C, irrigation location coefficient K_L and climatic variability coefficient K_{VC}, as well as leaching requirements LR. When these are not estimated in a rigorous manner, the results can affect irrigation efficiency and the profitability of the installation. Identifying the effects of simplifications made during agronomic design on the accuracy of the capability's operating parameters is one of the ways to contribute to agricultural food production, considering the rational and efficient use of water. The research used the design procedure proposed by Keller and Rodrigo/ 1979, and the hypothetical-deductive method was also used to evaluate the effects of simplifications in the operating parameters of the installation. As a result, arguments were obtained that allow establishing the effects of simplifications in the rigor of the results of the agronomic design of localized irrigation systems, which allow us to conclude that the rigorous agronomic design of localized irrigation systems with micro-sprinkling leads to establishing effective installations.

Keywords: Agronomic Design, Evapotranspiration, Micro-Sprinkling, Irrigation Timing, Irrigation Dose.

RESUMEN: Durante el diseño agronómico de sistemas de riego por microaspersión es difícil garantizar humedecer un volumen de raíces que permita la apropiada extracción de agua y nutrientes, así como el anclaje adecuado. Esto conlleva a extremar la precisión en esta etapa, esencialmente, en la estimación de los coeficientes de cultivo K_C, de localización del riego K_L y de variabilidad Climática K_{VC}, así como de las necesidades de lavado *LR*. Cuando la estimación de éstos no se realiza de manera rigurosa, los resultados pueden afectar la eficacia del riego y la rentabilidad de la instalación. Identificar los efectos de las simplificaciones realizadas durante el diseño agronómico, en la precisión de los parámetros de explotación de la instalación, constituye una de las maneras de contribuir a la producción de alimentos agrícolas, considerando el uso racional y eficiente del agua. En la investigación se utilizó el procedimiento de diseño propuesto por Keller y Rodrigo/1979, se empleó además el método hipotético - deductivo, para evaluar los efectos de las simplificaciones en los parámetros de explotación de la instalación. Como resultado, se obtuvieron argumentos que permiten establecer los efectos de las simplificaciones en el rigor de los resultados del diseño agronómico de sistemas de riego localizado, los cuales permiten concluir que el diseño agronómico riguroso de sistemas de riego localizado con Microaspersores conlleva a establecer instalaciones eficaces.

Palabras clave: diseño agronómico, microaspersión, evapotranspiración, duración del riego, dosis de riego.

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INTRODUCTION

Rodrigo *et al.* (1997) state that the key to the efficient design of an irrigation system is to establish as precisely as possible the performance that will later be required from the installation, as well as the knowledge of the parameters involved in the water-soil-plant-climate complex, topography, design restrictions, irrigation technic and others. In the case of localised irrigation systems, water is applied with a high frequency, which allows the salinity in the aqueous solution of the soil to be kept low and the absorption capacity of the roots to be maintained at adequate levels, due to the effect of the location of the irrigation (Pizarro, 1996a & 1996b).

Evaporation in these installations is lower than in conventional irrigation systems; on the other hand, transpiration increases slightly as a consequence of the effect of the location and the increase in thermal radiation on the crop canopy. These reasons mean that, in practice, coefficients are considered to differentiate the agronomic design of localised irrigation systems from that of other irrigation techniques. According to Pizarro (1996a) & (1996b), the use of these coefficients leads to different water needs and not taking them into account in a precise way during the design, means that the application of water is not adequate, either by excess or deficit.

Difficulties are sometimes encountered in obtaining the basic information needed to design localised irrigation systems, and the lax practice of incorporating simplifications during agronomic design has become widespread. The results derived from these simplifications may affect the efficient use of irrigation water and associated energy during the subsequent management of the installations; this leads to the excessive use of natural resources that are in deficit in the country. In this context, the following question arises: How do simplifications during the agronomic design of localised irrigation systems affect the precision of the operating parameters that have an impact on the rational use of water in these installations?

The aim of this paper is to establish arguments to answer this question by comparing the calculation results of two design variants in order to identify the effects of the simplifications made during the agronomic design of micro-sprinkler irrigation systems on the precision of the operating parameters of a citrus fruit localised irrigation installation.

MATERIALS AND METHODS

Draft state of the art

The FAO Penman-Monteith method according to Allen *et al.* (2006), represented an advance in the rigour of the procedures for estimating crop water requirements and is currently the most widely used by specialists in irrigation projects of the country's Agricultural Projects Companies (ENPA). Same authors have recently published some modifications that improve the rigour of this method and provide more accurate results (Allen & Pereira, 2009).

When localised irrigation systems are designed, they are inherently high frequency and can guarantee the crop a water potential in the soil consistent with its maximum consumption, without causing a significant increase in operating costs and initial investment, nor deterioration of the soil structure or damage to the crop (Pizarro, 1996a & 1996b).

In agronomic design practice, the use of the reference evapotranspiration for the 10 - 20% probability of exceedance ($ETo_{,P}$), based on monthly mean values measured at weather stations over 30 years or more, has become widespread. This value corresponds to the 90 - 80% probability rainfalls, which would cover the maximum crop demands 90 - 80% of the years. This practice is consistent with Jensen & Allen (2016), where it is proposed to use values of 10 - 20% probability of exceedance for high-demand crops. However, designers in Cuba use the unconvinced practice of using an ET_O value for each province, without considering local climatic conditions.

Authors cited by Pizarro (1996a & 1996b), suggest that when statistical processing is not possible, it is appropriate to consider a K_{VC} coefficient of climatic variability $1.15 \leq K_{VC} \leq 1.20$, to take into account the fact that the estimated evapotranspiration values correspond to values already measured and not to the maximum expected during the vegetative cycle, making it necessary to increase crop water to correct the deficit periods.

According to Pizarro (1996a & 1996b) the calculation of crop evapotranspiration ET_C does not present great differences with respect to other techniques. This is calculated by multiplying the crop coefficient K_C and the value of ET_O to the design probability, the resulting product is corrected by a coefficient due to the location of irrigation K_L, thus obtaining the evapotranspiration for Localised Irrigation ET_{Crl}.

The K_L coefficient has been determined by numerous procedures, which base their calculation on the fraction of the area shaded by the vegetation cover with respect to the total area, at noon on the summer solstice. In practice, four procedures are recognised and it is recommended to apply all of them, to eliminate the two extreme values and to use the average of the two closest values, however, in Cuba only one of these criteria has been adopted as valid.

The crop coefficient K_C is basically the quotient between the crop evapotranspiration (ET_C) and the reference crop evapotranspiration ET_O. It represents the integrated effect of the characteristics that differentiate a particular crop from the reference grass. Thus, each crop has a different value of the K_C coefficient which varies mainly with growth stage and to a lesser extent with climate.

Mahohoma (2016) compiles a wide range of K_C coefficients for citrus and his author attributed this dispersion to the diversity of climatic conditions and the particular characteristics of plantations, such as tree spacing and height, rootstock-cultivar combination, ground cover, management practices, irrigation technique and frequency of wetting. Although the K_C values provided by FAO-56 can be transferred between climatic regions using adjustment equations, they have limitations in considering the diversity of conditions between different plots.

Allen & Pereira (2009) proposed the A&P approach for more accurate estimation of K_C from physical parameters of the plantation, but Taylor *et al.* (2015) exposed the need to specify the influence of stomatal control manifested by citrus on these K_C values. In this sense, Pereira *et al.* (2021) updated the A&P approach based on the K_C resulting from the most relevant research, including those reviewed by Rallo *et al.* (2021) for citrus. Recently, Fernández-Hung *et al.* (2022) calculated representative Kc values for citrus for Cuban conditions, based on the updated A&P approach, which are higher than those adopted in Cuba as a reference for the design $K_C = 0.75$.

A further correction is made by means of the advection coefficient K_{ADV}, which takes into account the effect of adjacent crops. Depending on the area they occupy and their characteristics related to the transmission of moisture by wind, they can reduce the irrigation water requirement or increase it in case the adjacent crops are mostly dry. This coefficient is very difficult to estimate and in design practice, it is accepted not to consider it until its value is precise for specific conditions. $K_{ADV} = 1$.

Another important issue is the dimensions of the wet bulb generated by the emitters under the plants, which allow an appropriate volume of roots to be wetted or, as has been adopted in practice, an appropriate wetted percentage of the living surface of the PH_R crop. In the case of techniques that use air to apply water to the plants, an initial estimate can be obtained graphically by drawing to scale the horizontal projection of the tree crown according to its diameter, and in the same drawing the neighbouring plants in the same row and, preferably, the adjacent rows are indicated. The irrigation lateral and its location in relation to the row of plants are also indicated, as well as the emitters with their respective wetting bulbs, also in horizontal projection.

After obtaining the wetted area of several plants, the average wetted area per plant is determined and the percentage that this represents of the total vital area of the PH_R crop is calculated. From a design point of view, it is important to guarantee a wetting percentage equal to or higher than the minimum established for each $PH_R \geq PH_{MIN}$ crop.

Table 1 gives approximate values for the minimum wetting percentage suggested by various authors, for different crops.

TABLE 1. Minimum wetting percentage.

Author	Description	PH_{MIN} (%)
Torralba (1990)	Citrus and Fruits	25-35
	Banana	40-60
	Coffee	30-40
	Horticultural crops	50-70
	Hidroponics and pots	100

Source: Rodrigo *et al.* (1997)

The PH_R parameter is decisive for the yield of the crops and the profitability of the installations; it therefore influences the rational use of the water and energy resources designed for each installation. However, it is the effectively wetted root volume that is of interest, i.e. the volume at which a soil moisture content equivalent to the field capacity is guaranteed. In design practice, these values are very difficult to establish, more for practical than technical reasons, especially for systems using drip emitters, even though their estimation has an important experimental component, there is no justification for not doing so for micro-sprinklers. This is especially true if one takes into account that most designs ignore the effective radius of the Re_{ef} emitter, which allows to obtain the effective separation between them Se_{ef} to provide the appropriate value of PH_R. In most cases, the use of approximations when estimating this parameter leads to difficulties for the proper operation of the installation, especially when it is not taken into account during the design.

The uniformity coefficient CU also plays a role, its value is not a design objective, but a condition that is imposed and correlates constructive and hydraulic factors. It can be used in the evaluation of installations in operation and in the design of new systems, for which it is more demanding. The procedure is based on the calculation of pressure and flow rate tolerances, according to USDA-NRCS (2013): Rodrigo *et al.* (1997), defined the reasons justifying the use of this procedure:

1. The outlet diameter ($\varnothing_s$) of the emitters is much smaller than that of those used in sprinkler irrigation, generally its value ranges between $0.8 \leq \varnothing_s \leq 1.2$ mm, this implies that the risk of clogging is much greater in localised irrigation emitters.
2. Not all emitters leave the factory with the same ($\varnothing_s$), due to the wear that the moulds undergo during the anufacturing process, this detail affects

the uniformity of delivery of the emitters in the irrigation plot, when considering Cv_f and Ne, the construction factor is taken into account with greater rigour in localised irrigation systems.

3. The incidence of winds on the shape and dimensions of the wet bulbs generated is significantly lower, mainly in drip and exudation techniques.

Deliberately assuming CU, or not taking it into account in estimating total crop requirements, contributes to impairing the productive response of crops, ignoring Cvf can lead to the same results. During the calculation of total requirements, it is sometimes difficult to access data indicative of the salt content in the irrigation water or in the aqueous extract of the soil. This difficulty has led to use as a criterion to increase the net water requirement Nn, a fraction equivalent to the irrigation efficiency to anticipate water losses by deep percolation, as is done in the design of sprinkler irrigation systems. However, not applying this criterion may affect the productive properties of the soils and contribute to the accelerated deterioration of the installation (Table 2).

Location of the study area

Is located in the Empresa Agropecuaria Jiguaní, in the eastern region of Cuba, downstream of the confluence of the Cauto and Contramaestre rivers. Located 35 km northeast of Bayamo, the provincial capital of Granma, at the geographical coordinates 20°31'25" north latitude and 76°20'24" west longitude, at an altitude of 50 m.

Figure 1. Satellite photo of the study area.

Edaphoclimatic characteristics

According to Pérez *et al.* (2012) and in accordance with the World Reference Soil Resource Base WRB, the soil is classified as Calcaric Fluvisol, with moderately fine textures. Waller and Waller & Yitayew (2016) refer that its main hydrophysical properties are:

1. Retention capacity (14 to 16% V).
2. Final infiltration rate (mm h-1).

From the Köppen-Geiger climate classification, it was obtained that in the area there is an equatorial climate of savannah with dry winter Aw Kottek *et al.* (2006), and in the aridity map of Cuba, it was observed that in the study area there is a semi-humid-humid aridity regime (Vázquez *et al.*, 2016). The main climatic variables are shown in Table 3.

TABLE 3. Main climatic variables.

Hyperannual average rainfall (mm)	779
Average wind speed (m/s)	1.2 - 2.5
Average monthly temperature (°C)	22.3 - 26.5
Monthly average relative humidity (%)	74.1 - 83.5

Source: Fernández-Hung *et al.* (2022)

Crop characteristics

The crop to be used is 'Marsh Jibarito' grafted on sour orange (Citrus paradisi Macfad.), grafted on sour orange (Citrus aurantium L.). The expected characteristics for 10-year-old trees, taken from experience, are given in Table 4.

TABLE 4. Expected crop characteristics.

Planting frame (m × m)	6 × 4
Avareage diameter of the cup (m)	4,0
Avaerage height (m)	4,5
Depht of active roots (m)	0,6

Characteristics of the supply source

The irrigation water is pumped from the Contramaestre river, the values of the electrical conductivity were obtained from the 1991-2019 series

TABLE 2. Recommended design uniformity coefficients.

Type of issuer	Spacing	Topography	Pending (%)	Rank of CU (%)
Linear font in annual and perennial crops	All	Uniform	< 2	80 - 90
		Steep or undulating	> 2	70 - 85
Micro-sprinkling	All	Uniform, Steep or undulating	< 2	90 - 95
			> 2	80 - 90

Fuente: USDA-NRCS (2013)

of values measured between the months of January and April. Their most representative values are shown in Table 5, including the one corresponding to the 10% probability of exceedance.

TABLE 5. Electrical conductivity values of irrigation water.

CE $_{ar}$ **(dS m** $^{-1}$ **)**	0.4 - 3.3
Average *CE* $_{ar}$ **(dS m** $^{-1}$ **)**	1.0
D Statistical *CE* $_{ar}$ **(dS m** $^{-1}$ **)**	0.57
CE $_{ar\ 10\%P}$ **(dS m** $^{-1}$ **)**	1.8

Source: Redcal (2019)

Characteristics of the micro-sprinkler available

The technical characteristics of the micro-sprinkler used are shown in table 6.

TABLE 6. Characteristics of the micro-sprinkler ACUASMART 2002.

Working pressure (kPa)	150 -400
Flow rate (L/h $^{-1}$ **)**	20
Wetting diameter (m)	3.0
Nozzle diameter (mm)	0.84

Source: Redcal (2019)

Calculation approach

The effects of agronomic design simplifications on the operating parameters of localised irrigation systems were determined by comparing the results of two calculation variants in a micro-sprinkler irrigation system project for the citrus plantations to be promoted in areas of the agricultural company "Jiguaní". In variant A, the simplifications of the agronomic design described above were incorporated and variant B was calculated according to the procedures described in the updated technical literature, without the use of the above-mentioned approximations during the design.

Procedure for agronomic design

Net water requirements [N_n (mm d^{-1})]

Calculated from the expression proposed by Rodrigo, (1997):

$$Nn = ETo \quad Kc \quad K_L \quad K_{VC} \quad K_{ADV} \quad (1)$$

Where:

ETo: Reference Evapotranspiration (mm d $^{-1}$).

Kc: Crop coefficient (dimensionless).

K_L : Location coefficient (dimensionless).

Kvc: Coefficient of climatic variation (dimensionless).

K_{ADV} : Coefficient of advection (dimensionless).

In variant A, a value of ETo = 4 mm day-1 was adopted. For variant B, given the absence of reliable solar radiation data from nearby agro-meteorological stations and the simplicity of the method in relation to the FAO Penman-Monteith method, the ETo value was calculated using the Hargreaves-Samani equation Paredes *et al.* (2020), from the series of climatic data obtained from the agro-meteorological station of Contramaestre, and its values were statistically processed to obtain the 10% probability of overshoot, so that in this case Kvc = 1.

For variant A, a single value of the crop coefficient, Kc = 0.75, suggested by the Technical Design Task, was taken, and for variant B, the value of Kc = 0.93 for the peak period Fernández-Hung *et al.* (2022), calculated according to the Allen and Pereira (A&P) approach, was adopted. To obtain (K_L) the criterion of the fraction of the area shaded by the crop was followed. For variant A, only a (2b) was used and for variant B, the two resulting intermediate values were

$$\text{Averaged}.\, K_L = 1.34 \quad PC \quad (2a)$$

$$K_L = 0.1 + PC \quad (2b)$$

$$K_L = PC + 0.5\,(1 - PC) \quad (2c)$$

$$K_L = PC + 0.15\,(1 - PC) \quad (2d)$$

Where:

PC, is the fraction of area shaded by the crop, which was obtained by the last of the equalities shown below.

$$PC = \frac{A_{PV}}{A_{MP}} = \frac{A_C}{A_{MP}} = \frac{S_P \quad \phi_C}{A_{MP}}$$

A_{MP}: This is the area of the planting frame (m^2).

A_C : This is the area of active roots (m^2). It is applied in the case of crops that do not have a defined canopy and can be determined graphically according to the planting frame, the arrangement of the emitters in relation to the plants and the area wetted by the emitter.

A_{PV}: It is the area of the vertical projection of the tree crown measured at noon on the summer solstice (m^2). It is applied in the case of crops with a defined crown; its value must be obtained experimentally.

S_P : Plant spacing between plants in the same row (m).

$\varnothing_C$: Diameter of tree crown (m^2), applies with the same specifications as for (A_{PV}).

Total water requirements [*Nt* (L p $^{-1}$ d $^{-1}$)]

For variant A the flushing requirement (LR=K) was not taken into account to increase the water requirement of the crop, only the risk of percolation losses from the application efficiency (E_{AP} = 90%) was taken into account. The leaching requirement (K) was taken into account for variant B, as it was possible to obtain the salinity of the irrigation water (ECiw). The maximum electrical conductivity of the aqueous soil extract in the root zone, maxECse, that the crop tolerates (100% yield impairment) was estimated at 8 dS m^{-1} (Zaman *et al.*, 2018).

$$Nt = \frac{Nn \quad A_{MP}}{\frac{CU}{100} \quad (1-K)} \qquad (3)$$

Where:

$$K = max\left[\left(1-\frac{E_{AP}}{100}\right), \quad LR = \frac{CEar}{2máxCEse}\right] \qquad (3a)$$

Actual wetting rate [PH_R (%)]

$$PHr = \frac{Ah_R}{A_{MP}}100 \geq PH_{MÍN} \qquad (4)$$

Where:

$PH_{MÍN}$: Minimum wetting rate necessary to ensure plant development, generally assumed from specific research, $PH_{MÍN}$ = 35% (Table 1).

A_{MP} : Area of planting frame of plant (m^2).

Ah_R : Actual wetted area per plant (m^2), when a continuous wetting band is to be achieved, it can be estimated by means of:

$$Ah_R = Ne\ Ae \qquad (5)$$

$$Ae = \pi(1.1 \quad Re)^2 \left(\frac{\propto}{360°}\right) \qquad (5a)$$

Where:

Ne: Number of emitters per plant (u).

Ae: Surface that wets an emitter (m^2).

Re: Radius of reach of the emitter (m). Some authors propose to increase this value by 10 -15% depending on the soil texture, others do not foresee such an increase in order to stay on the safe side. According to Vargas-Rodríguez *et al.* (2021) it is more rigorous to use (Re_{ef} = 1.1 (*Re*).

α: Diffuser outlet angle.

The Ah_R value was estimated graphically, taking into account that irrigation is applied through a continuous wetting strip, as well as the percentage it represents in relation to the area of the A_{MP} crop planting frame. In (5a), 10% of the emitter radius was not increased to calculate Ae, which would be on the safe side. The PH_R parameter should be checked graphically.

In localised irrigation systems, the storage capacity of the soil has no relevant use from a design point of view, because the high frequency typical of this irrigation option leads to small doses being applied and as a consequence the moisture content in the soil is always very close to the field capacity.

This characteristic leads to the fact that the soil storage capacity is not fully exploited and therefore some hydrophysical properties of the soil such as bulk density β, field capacity CC, do not have the same usefulness as they do in the design of sprinkler and surface irrigation systems.

From a design point of view, the soil storage capacity MN allows to obtain the maximum irrigation frequency that the soil can support IR_{MAX}. However, as a general rule localised irrigation systems are designed for daily application frequencies, therefore, the calculation and choice of the Irrigation Interval can be considered as a formal design step to establish a threshold value above which it is not feasible to space one irrigation from the other. Practice has shown that it is feasible to design for a daily frequency, due to the facility this represents to achieve a soil moisture regime that is conducive to the best crop yields.

Irrigation time [*TR* (h)]

$$Tr = \frac{Nds}{Ndr}\ \frac{Nt}{Qp}\ IR \qquad (6)$$

Where:

Nds: Is the number of days of the week (d).

Ndr: The number of days available for irrigation in the week. (d).

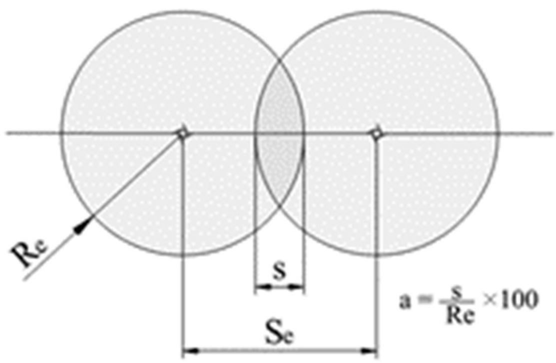
IR: Frequency of irrigation (d). *IR* = 1 d.

Q_P: This is the installed flow rate per plant (L h -1 p-1) and is calculated depending on the arrangement of the lateral pipe and the emitters with respect to the row of plants. For the case of continuous wetting strip:

$$Qp = \frac{Qe \quad Ahr}{Ae} = Qe \quad Ne \qquad (6a)$$

Where Qe is the average flow rate of the emitter (L h-1) corresponding to the working pressure and which guarantees the value Ae. The analytical solution of Q_P must not lose sight of the practicality of the above graphical solution for estimating PH_R. By locating the emitters along the lateral pipe with an equidistance (Se) and verifying their position with respect to the plants, valid criteria were obtained for estimating the number of emitters that wet the same plant and checking their value, obtained by means of (6.1).

$$Se = Re\left(2 - \frac{a}{100}\right) \qquad (6b)$$



Source: Pizarro (1996a) & (1996b).

FIGURE 2. Graphic representation of (Se).

Quotient (Nd_S/Nd_R) is justified because in many farms a day of the week is foreseen in which irrigation is not applied and system maintenance and agro-technical work is planned; this is done for distributing the irrigation dose of that day among the remaining six days of the week, considering that the irrigation frequency is daily. Approximating the duration of daily over irrigation by ¼h, which also facilitates the use of mechanical clocks for irrigation management is recommended. By extending the graph in the figure above, it is possible to identify the most representative wetting patterns on the irrigation lateral and to verify the position of each emitter along the row of plants.

Total irrigation rate [*Dt* (L $p^{-1}d^{-1}$)]

$$Dt = \frac{Trajustado \quad Qp \quad Ndr}{IRreal \quad Nds} \quad (7)$$

It was found that it meets the total water requirements of the plant (Dt ≥ Nt) and also that the average application intensity of the chosen emitter does not exceed the stabilised infiltration rate of the soil for the estimated time ($I_{AP} \leq V_{INF}$).

Specific research has shown that in localised irrigation systems the application intensity at the start of irrigation is higher than the stabilised infiltration rate of the soil, but as water movement takes place in the soil, the surface area wetted by the emitter increases considerably, reversing the previous situation until the volume of water expected to be applied during the design is achieved. If this is not achieved, the choice of the emitter or its working pressure must be reconsidered, another alternative would be to apply irrigation to pulses, assuming the use of certain automatisms Allen & Pereira (2009).

The application intensity [I_{AP} (mm h-1)] was computed by:

$$I_{AP} = \frac{Qe}{Ae} \quad (8)$$

RESULTS AND DISCUSSION

Agronomic design

The results of the agronomic design were obtained from the previous procedures. The table below shows the main results of the comparison, which corroborate how the use or not of certain coefficients and parameters can lead to two installations with different performances in the same soil and climate scenario, for the same flow emission device and the same crops.

TABLE 8. Results of the agronomic design.

Design parameters	Variants	
	A	B
Net water requirements (mm d^{-1})	2.7	3.6
Total water requirements (L p^{-1} d^{-1})]	79.2	108.0
Actual wetting rate (%)	46	46
Frecuencia de riego (d)	1	1
Irrigation time (h)	3.0	4.25
Total irrigation rate (L p^{-1} d^{-1})	80.0	113.3

Analysis of the results

The water requirements in variant B were higher than in variant A. In the latter, an installation has probably been designed with a lower initial investment cost, but limited agronomically and therefore with restrictions to operate under more demanding conditions; these can manifest themselves with the increase of salts in the soil solution and/or in the irrigation water. This constitutes a real risk in localised irrigation installations with deficient or absent drainage systems in the irrigated plots.

It was also influenced by the fact that only the Decroix criterion, quoted by Pizarro (1996a), was taken into account to estimate the irrigation location coefficient K_L = 0.77, instead of using the average value of the closest results, in the way it was conceived in variant B where K_L = 0.74. On the other hand, the crop coefficient K_C = 0.75 was taken for variant A, a value suggested in the Technical Task of projection and more updated proposals were not taken into account for its estimation (Fernández-Hung *et al.*, 2022).The latter researchers obtained K_C = 0.93 for the specific conditions of the study area and tall trees, planted at high planting density.

In variant A, the probable value of the most critical reference evapotranspiration used for the design ETo = 4 mm/d, value suggested in the Technical Task, was not obtained from a statistical procedure for data analysis, its adjustment was made assuming the correction coefficient for climatic variability (K_{VC} = 1. 175), this led to the net needs estimated for the period of maximum crop demand, Nn = 2.7 mm d-1, instead of Nn = 3.6 mm d-1 obtained for variant B, which resulted in a more flexible value for possible climatic and more demanding operational disturbances.

In variant A, leaching requirements were not taken into account and Nt was increased from the application efficiency (E_{AP} = 90%) and thus the denominator of (3) is 81% (similar to the irrigation efficiency value used in the design of most sprinkler irrigation techniques). In contrast, in variant B, Nt increases with the leaching fraction, obtained from (4), where the electrical conductivity of the irrigation water ECiw = 1.8 dS/m and in the aqueous soil extract maxECse = 8 dS/m.

In both variants, the percentage of wetted area exceeds the expected minimum, even though what really matters is the volume of wetted roots. This issue is not properly ensured due to the aforementioned disadvantage of not carrying out field tests prior to the design of the installations, making it impossible to ensure this objective during the design stage. However, it has been proven that the volume of wetted soil under the emitters is greater than the volume of wetted soil that accumulates on the surface. Providing for more than 35 % of the wetted surface, as shown in Table 6, provides a guarantee of wetting the appropriate root volume below the emitters.

It is important to carry out the graphic procedure described above. Figure 3 shows the distribution of moisture patterns along the row of plants, useful for estimating PH_R and verifying Ne in the case study. This, which is supposedly solved by guaranteeing a minimum wetted surface of the vital area of the plant, can lead to applying volumes of water higher than the total needs, since, as previously specified, below these, the volume of wetted roots is much greater as they are concentrated in the wet zone, and thus the application of irrigation could be more costly when the wetted surface is exaggeratedly greater. It is also impossible to ensure during design that the moisture content under the plants is equal to or slightly higher than field capacity of the soil, otherwise there would be a reduction in yields and profitability of the installation.

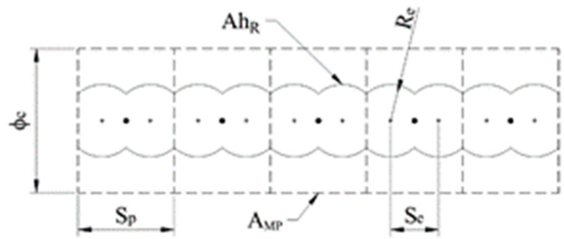


FIGURE 3. Moisture patterns along a plant row.

Failure to carry out the field tests results in a further simplification of the design which may lead to changes in the operating parameters of the installations. The effects of this simplification are valid for both variants, although its repercussions are more detrimental in variant A. According to Vargas-Rodríguez *et al.* (2021),this situation is aggravated in drip irrigation techniques.

In variant A, the irrigation time is 3 h, and the rotational units will be able to group more plots than in variant B, in which more than 4.25 h are needed to apply the necessary dose. This, which in principle would seem to be an advantage of variant A, might not be the same when the hydraulic scheme of the installation and its hydraulic design is conceived; since assimilating this advantage would imply greater lengths and diameters of pipes to be able to take the water to the plots located at the ends of the installation, the energy losses would be greater and therefore the necessary performance of the pumping installation would also be higher.

From the above analysis, variant A stands out as an installation with a lower initial investment cost, but this is not definitive; design practice has shown that what represents a saving at the agronomic design stage may turn out to be the opposite at the hydraulic design stage and the installation would continue to be agronomically restricted and with limitations to operate under more demanding conditions.

CONCLUSIONS

The lack of rigour in the acquisition and use of basic data for the agronomic design of micro-sprinkler irrigation systems leads to installations with limitations to operate under more demanding conditions.

One of the most widespread simplifications of agronomic design procedure is related to the flushing requirements, not taking into account this parameter can lead to dangerous accumulation of salts in the soil solution, decrease in crop yields and subsequent deterioration of the productive properties of the soil.

The application of simplifications at the stage of agronomic design of the installation does not necessarily lead to more flexible and economical hydraulic schemes, and pumping parameters may become more demanding.

Although the volume of roots wetted tends to be sufficient when the surface area wetted by the emitter exceeds the established minimum, field tests are more reliable in micro-sprinkler irrigation systems, as they allow verifying the moisture content under the emitters and the actual effective wetting radius of the emitters.

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