ORIGINAL ARTICLE

Influence of the Effective Wet Bulb on the Design of Drip Irrigation Systems

Influencia del bulbo húmedo efectivo en el diseño de sistemas de riego por goteo

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ABSTRACT: In drip irrigation, the volume of wetted soil represents the amount of water stored and its shape and dimensions should correspond to the plant root system and the spacing between emitters, however in design practice, the effective wetting radius reached by these devices is not considered. The results of the agronomic design obtained with different design procedures are compared and their effects on operating parameters are identified. The analysis and synthesis method was used, based on the comparison of three design procedures, one using the criteria set out by Arapa /2002, the second, taking into account the criteria set out by Cruz-Batista et al. /2015 and the third using the alternative procedure applied in the UEB Consultancy and Design of the ENPA. The results showed the feasibility of using experimental models for the design of drip irrigation systems, given the impossibility of carrying out field tests; these tools make it possible to predict the lateral and vertical advance of water under the emitters. It was found that moisture transfer under the emitters is a function of the volume of water applied, the flow rate of the emitter, the saturated hydraulic conductivity, the initial and residual moisture content and the silt content of the soil. The comparison allowed affirming the validity of using simulation models to estimate the emitter spacing necessary to wet the required soil volume.

Keywords: Effective Radius, Wet bulb, Effective Wetting, Agronomic Design, Drip Emitters.

RESUMEN: En el riego por goteo, el volumen de suelo mojado representa la cantidad de agua almacenada y su extensión, profundidad y diámetro deben coincidir con el sistema radicular de la planta y el espaciamiento entre emisores, sin embargo, en la práctica del diseño, no se considera el radio de humedecimiento efectivo que alcanza estos dispositivos. Se comparan los resultados del diseño agronómico obtenido con procedimientos concebidos para condiciones específicas, y se identifican los efectos que sobre los parámetros de explotación ejerce los parámetros de diseño. Se utilizó el método de análisis y síntesis, a partir de la comparación de tres procedimientos de diseño, uno empleando los criterios expuestos por Arapa /2002, el segundo, teniendo en cuenta los criterios expuestos por Cruz-Batista et al. /2015 y el tercero utilizando el procedimiento alternativo que se aplica en las UEB de Consultoría y Diseño de la ENPA. Los resultados mostraron la viabilidad de utilizar modelos experimentales para al diseño de sistemas de riego por goteo, ante la imposibilidad de realizar pruebas de campo, estas herramientas permiten prever el avance lateral y vertical del agua debajo de los emisores. Se constató que la transferencia de humedad debajo de los emisores, es función del volumen de agua aplicada, el caudal del emisor, la conductividad hidráulica saturada, el contenido de humedad inicial y residual y de limo en el suelo. Esta comparación permite afirmar la validez de utilizar modelos de simulación para estimar la separación entre emisores necesarios para humedecer el volumen de suelo requerido.

***Palabras clave*:** radio efectivo, bulbo húmedo, humedecimiento efectivo, diseño agronómico, emisores de goteo.

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INTRODUCTION

In drip irrigation, the water supply is used to maintain moisture in the root zone under low tension conditions. Keller & Bliesner (1990), considers that the wet bulb obtained normally reaches its maximum diameter at a depth of approximately Hernández (1990) proposes that it should be based on the dense branching zone of the crop, specifically at a depth of between 90 and 120% of this.

For design purposes, the important thing is to guarantee a volume of moistened roots that favours the extraction of water and nutrients by the plants, as well as their anchorage in the soil, but in practice, the use of the surface area moistened by the emitter has become generalised, which is an easier parameter to obtain and allows an approximate estimate of the number of emitters that moisten the same plant. In this sense, Dorta (2017) have developed research that addresses the optimum humidity of the wetted area in the systems, which is still inconclusive.

Arapa (2002) corroborates Hernández (1990) and states that the depth of the bulb should be between 0.9 and 1.2 of the depth of the roots, the shallower the bulb, the greater the number of emitters and the greater the efficiency from an agronomic point of view, but the installation is more expensive. The greater bulb depth may be more suitable to act as a flushing fraction for salinity control, unless the water quality requires a higher flushing fraction, in which case the bulb depth restriction expressed above is not considered. It is also possible to find a linear correlation with pairs of field volume and depth data obtained in the field.

According to Arapa (2002), both depth and wetted diameter can be determined by the following methods: a) field tests, b) formulae and c) tables. Given the great heterogeneity of soils, formulae and tables should only be used very cautiously in the design, with direct field measurement being much more reliable. This situation has led to the application of alternative design procedures that do not consider field tests, with the result that the rational and efficient use of irrigation water is not guaranteed, either by over- or under-application.

Authors such as Amin & Ekhmaj (2006); Elmaloglou & Diamantopoulos (2009) and Cruz-Bautista *et al.* (2015), claim that if the distribution of water within the wetted soil volume is known, the emitter(s) can be located and managed in such a way as to ensure accurate placement of water and nutrients in the root zone of the plants (Allen *et al.*, 2006). Design procedures that take into account the characteristics of this distribution lead to a more rational use of irrigation water in the installations (Pizarro, 1996; ASABE, 2007; Cruz-Bautista *et al.*, 2016).

In this sense, the purpose of the research is to establish technical criteria that demonstrate the validity of considering the effective diameter produced under the drip irrigation emitters from the design of the installations and the importance of using computer tools to estimate the transfer of humidity under the emitters, given the practical impossibility of carrying out field tests.

MATERIALS AND METHODS

Identification of the Technical Task

The Technical Task was prepared by the Agricultural Research Institute (IAgric), at the request of the Agroforestry Group (GAF) and under the supervision of the Technical Evaluation Committee (CTE) of Irrigation and Drainage, the information contained in it was used in the agronomic design of the three variants: one, using the proposal of Arapa (2002), the second variant applying the experiences obtained by Cruz-Bautista *et al.* (2015) and the third variant, using the alternative procedure widely used in practice.

Characterisation of the Water - Soil - Plant - Climate complex

Source of supply

The source of supply is the Contramaestre river, belonging to the homonymous municipality in Santiago de Cuba province. The irrigation water is pumped from the left bank of the river at a point located 200m from the confluence with the Cauto river. As a measure of the salinity, the electrical conductivity (Pizarro, 1996).

Due to its influence on the results of the agronomic design and on the a posteriori management of the irrigation water of the installation, this parameter must be verified and its behaviour controlled during the useful life of the irrigation system, due to the fact that the salinity of the water contributes to clog the small outlet diameters of the drippers, especially when the nature of the salts is more dangerous, the supply source is considered suitable for irrigation of the proposed crop (Pizarro, 1985; 1990).

Soil data

Sandy soils have low water storage capacity and high infiltration value. Therefore, they require frequent application of small irrigations, especially when the soil is not only sandy but also shallow. Under these circumstances, low pressure sprinkler irrigation and localised irrigation are more suitable.

The soil of the case study is characteristic of the mountainous area, with uniformly undulating relief, with slightly gentle slopes in the irrigation plots, the value of the stabilised infiltration rate of the soil is not known. It was planned not to locate the lateral pipes on the slope to avoid the possible risk of surface runoff, and the low application intensity of the drippers was also taken into account. The electrical conductivity data in the soil saturation stratum were not provided. For the design of variants 2 and 3, an EC value of 2.3 dS/m was assumed for similar crops and for a 10% effect on production (Pizarro, 1985).

Characteristics of the crop to be processed

The beneficiated crop is Robusta coffee plant, with a planting frame of 3 m between rows and 3 m between plants, with a depth to wet of 0.40m and a crop coefficient in the middle phase of the vegetative cycle = 1.04. According to Vigoa-Hernández (2000) the crop tolerance to flooding ranges between 2 and 3 days.

Climatic data

The values of the direction and speed of the prevailing winds are not known, nor are the altitude of the area, temperature, Relative Humidity and the speed and direction of the prevailing winds. Only the data referring to the evapotranspiration of the reference crop were provided, according to the Technical Task, ETo = 3.95 mm/d was used in correspondence with the eastern region of Cuba.

Irrigation aggregates

For the design of drippers integrated in the pipe, self-compensating, self-cleaning, anti-root, anti-suction, with the lateral pipes buried. According to the information of the Technical Task, the dripper flow rate = 4 L/h separated at 0.60 m along the lateral, so that the number of emitters per plant guarantees to wet 50% of the vital area of the crop and to form a continuous wetting band. For the design of variant 1, a location coefficient (KL = 0.67) and a uniformity coefficient (CU ≥ 90%) were used.

For the three design procedures, category "A" emitters were considered, endorsed by laboratory tests according to NC ISO 8026: 2014 (2014) and UNE 68-075-86, 68-076-89 standards mentioned for Reyes-Requena *et al.* (2023). It is recommended that the flow-pressure ratio of the emitter and the manufacturing coefficient of variation (CVF) be less than 5%. The laterals must be easily removable and with threaded nipple - thread connection.

Agronomic design procedures for drip irrigation systems

According to Pizarro (1996), the agronomic calculation is the part of the design where errors have the most serious consequences, besides, it is guaranteed to estimate with optimum efficiency the water needs of the crop during the period of maximum demand, avoiding at the same time the salinisation of the soil due to lack of washing or the insufficiency in the volume of soil wetted by installing the wrong number of emitters (Vargas, 2004).

The same author states that in order to achieve an appropriate design, a suitable number of emitters and their flow rate must be foreseen in each case, determined according to the physical properties of the soil and the irrigation dose to be applied, and assures that the shape of the wetted areas provides elements of judgement to choose the most correct arrangement of emitters and laterals.

Crop response to irrigation application, as well as other economic criteria such as water cost, crop value, etc., are the basis for deciding the application efficiency. Keller & Bliesner (1990) stresses that the estimation of application efficiency (Eap) must take into account the climate of the area, and the possibilities of considering or not the effective precipitation for the calculation of the net requirements (Nn) (Schwartzman & Zur, 1986; Ramírez & Sainz, 1997).

On the other hand, the crop's tolerance to salinity and the quality of the irrigation water can increase the net irrigation needs with some fraction of flushing, this quantity must be increased with the application efficiency to ensure that the plants that receive less water have enough to satisfy the total irrigation needs.

To supply these needs, various combinations of doses and frequencies can be chosen and these should

TABLE 1. Hydrophysical properties of the soil. Source: Technical Task

Texture	Cc (% V)	PMP (% V)	LSAD (mm)	LIAD (mm)	ADP (mm)	RFU (mm)
Sandy	26	13	104	52	26	10

Cc- moisture at field capacity expressed in % volume.

PMP- moisture at permanent wilting point expressed in % volume.

LSAD and LIAD- water tables corresponding to the maximum (Cc) and minimum (PMP) values of water available in the soil, expressed in mm.

ADP- total water available in the soil for plants, expressed in mm.

RFU- plant water useable reserve equivalent to the partial net irrigation standard, expressed in mm. The wetting depth considered for these calculations is 0.4 m and the criterion for defining the time of irrigation during operation is 90% of the moisture value at field capacity.

be tested in conjunction with the flow rate of the emitters to determine what number of emitters would be required to achieve the appropriate soil volume (Camp, 1998; Kandelous & Šimůnek, 2010). Once all these values have been determined, the irrigation time can be calculated, which is a defining parameter in the design of the operational unit (Bainbridge, 2001). The agronomic design also provides the basic data for the hydraulic design (Vargas, 2004).

Variant 1: Agronomic Design according to (Arapa 2002)

Pizarro (1996) asserts that, in order to guarantee a soil moisture content corresponding to the water requirements of the crop, it is important to delimit the value of the number of emitters (e) that guarantees the minimum percentage of wetting (PHmín) around the root system; and to define the volume delivered by the emitter (Ve) and made available to the plant very close to this zone (90%Prad ≤ Pb ≤ 120%Prad). To determine the bulb diameter, the equation expressed by Arapa (2002) for coarse soils (sand) was used as a function of the emitter flow rate.

Calculation of wetted diameter [ϕmoj (m)].

$$\phi_{moj} = 0.3 + 0{,}12 \times q \quad (1)$$

where:

q- flow delivered by the emitter in (L/h), once the wetted diameter was obtained, it was divided by 2 to obtain the wet bulb radius.

Calculation of the surface area wetted by the emitter [Ae (m^2)].

$$A_e = \pi \times \mathrm{Re}^2 \quad (2)$$

where:

Re: radius that wets the dripper (m), obtained in the previous step.

Minimum number of emitters per plant [e (u)].

$$e \geq \frac{A_{mp} \times (PH_{min})}{(A_e \times 100)} \quad (3)$$

this value ensures that the percentage of wetted area of each plant is higher than the minimum set.

where:

Amp: area of the planting frame (m^2).

PHmín: Minimum wetting percentage.

$$\text{Irrigation time}[\mathrm{TR}(h)]\,.\,T_R = \frac{N_T}{e \times \mathrm{Qe}} \quad (4)$$

where:

Qe: Flow delivered by an emitter.

N_T- Total requirements (mm/d), this value was determined by:

$$N_T = \frac{N_N}{\mathrm{cu}^*(1-k)} \quad (4.1)$$

where:

CU: Coefficient of uniformity (%).

N_N: Net requirements (mm/d), this value was determined by:

$$N_N = ETo \times Kc \times K_L \times K_{VC} \times K_a \quad (4.2)$$

where:

ETo: Evapotranspiration of the reference crop (mm/day).

Kc: Crop coefficient (adm).

Ka: Coefficient of advection (adm), assumed=1, until its value for Cuban conditions is specified.

K_L: Coefficient due to irrigation location (adm).

Kvc: coefficient of climatic variability (adm), Hernández (1990) quoted by Pizarro (1996), proposes a value between (1.15-1.2).

K: Leaching requirements or possible percolation losses, determined by:

$$K = 1 - \mathrm{Ef}_{ap} \quad (4.3)$$

$$K = \frac{\mathrm{EC_{iw}}}{2^*\mathrm{EC_{se}}} \quad (4.4)$$

where:

EC_{iw}: Electrical conductivity of irrigation water (dS/m).

EC_{se}: Electrical conductivity of the soil saturation layer (dS/m).

Of the two calculated values of (K), the higher value was chosen. If the percolation losses are higher than the flushing requirements, these losses would lead to a higher flushing than necessary, thus keeping the salinity level below the minimum. If, on the other hand, the losses are lower than the flushing requirements, a higher percolation would have to be provoked voluntarily to avoid salinisation of the soil (Pizarro, 1996)

Calculation of the total dose [D_T (L)].

$$D_T = Tr_{\ ajustado} \times e \times Qe \quad (5)$$

The following comparison was used as a design constraint:

$$Dt \geq Nt \quad (6)$$

Variant 2: Agronomic design according to Cruz-Bautista *et al.* (2015)

The same procedure as in variant 1 was used, but using the criteria established by these authors for the calculation of the wet bulb radius, based on the experimental model developed. Cruz-Bautista *et al.* (2015) state that knowing the distribution of water under the emitters in drip irrigation systems is a requirement for their design and operation, since one of the most important parameters in the design is the shape and volume of the bulb that forms under the emitters.

The volume of wetted soil represents the amount of water stored in the soil; while its extent, depth and diameter must take into account the depth of the plant's root system and the spacing between emitters. According to these authors, the volume of soil wetted and its extent is a function of soil texture and structure, saturated hydraulic conductivity and initial moisture content, as well as the flow rate applied by the emitter (USDA, 2013)..

Variables, such as the relative position of the emitter, amount and frequency of irrigation, temporal and spatial changes in soil moisture content, affect soil moisture transfer. Cruz-Bautista *et al.* (2015) experimentally determined the bulb radius, for a flow rate of (4 L/h) in sandy soil and obtained an experimental model part of these results are shown in Figure (1).

Variant 3 of Agronomic Design according to the alternative procedure

It is used due to the impossibility of carrying out field tests, in spite of being the most used procedure for the design of drip irrigation systems in Cuba, it does not take into account parameters such as; the radius that wets the emitter, the depth at which the wet bulb develops and the volume of water delivered by the emitter which is estimated in function of satisfying the evapotranspiration demand without taking into account the washing needs, being the time of application the corresponding one so that the previously mentioned condition is fulfilled.

The agronomic parameters that were not considered in this procedure are necessary for the analysis of the water-soil-plant complex, therefore, not taking them into account during the design of the systems will surely lead to the application of irrigation water not being carried out in an adequate manner for the crop, either due to excess or lack of liquid, Vargas-Rodríguez *et al.* (2021).

The number of emitters required to meet the total water needs of the plant is estimated proportionally to the volume required to meet the water needs along the row of plants, based on the nominal flow rate of the emitter and the number of plants in the row. The "volume of water needed for each plant" is provided, based on assuming the irrigation duration suitable for this purpose; contrary to the two previous variants, where the irrigation duration is obtained based on the total water needs, the soil - plant ratio and consequently the installed flow rate per plant.

In this variant, the duration and frequency of irrigation were assumed at the convenience of the farm, providing that (6) is met, the water needs of the plant are maintained: the N_N and N_T parameters were obtained in the same way as in variants 1 and 2, with the particularity that the leaching needs (K) were calculated only with the expression (4.3), without considering the salt content.

As the final dose and irrigation duration were obtained from the number of plants along the row and the total water requirements of each plant, the length of the lateral and the spacing between drippers along the lateral are important parameters to consider in the design, from which it is possible to know the flow rate delivered to the entire row of plants.

This variant has been generalised in the design practice in Cuba, due to the practical difficulties of carrying out field tests. In order to make the comparison between the variants more valid, the initial data were maintained and a total of 20 plants per row and the separation between emitters = 0.6 m was assumed; this meant that a volume corresponding to the total needs of all the plants in the row was applied to the lateral, for which 101 emitters were used.

RESULTS AND ANALYSIS

Agronomic design of the irrigation system

The results obtained in the design of each variant are compared (Table 2 y Figure 2), taking into account data corresponding to real field tests, those referred to in the Technical Task and other parameters that have been conveniently assumed by the author. This leads to evaluate the advantages and disadvantages between them, mainly focused on the integrated and sustainable management of irrigation water and energy in times of climate change.

The first variant, developed from the procedure proposed by Arapa (2002), is based on the textural classification of the soil, based on which an equation is used to estimate the diameter wetted by the dripper from the flow rate it discharges. The second variant

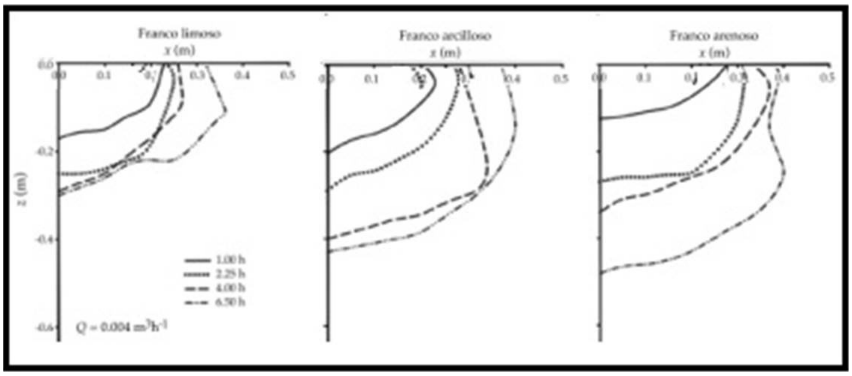


FIGURE 1. Advance of the wetting front (Cruz Batista et al., 2015).

TABLE 2. Results of the agronomic design in each variant

Parameters	1st Variant	2nd Variant	3rd Variant
Wetting radius. [Re (m)]	0.39	0.35	-
Wetted surface area. [Ae (m^2)]	0.478	0.384	-
Number of drippers per plant. [e (u)]	6	7	≈ 5
Net requirement.[N_N (mm/d)]	3.30	3.30	3.30
Total requirements. N_T (L/d/p)	44.68	44.68	36.69
Timming Irrigation. T_R (h)	1.87	1.6	5.45
Irrigation deep. D_R (L)	44.88	44.88	36,91

uses the previous procedure, but the diameter wetted by the dripper is obtained from the experimental model developed by these authors, specifically represented for clay-textured soils in Figure 1, where the vertical and horizontal displacement of the wet bulb is estimated when using drip emitters under specific conditions.

A third variant was also considered, corresponding to the alternative design, which does not present many coincidences with that documented by Pizarro (1996), justified by the impossibility of carrying out field tests, as well as the lack of professional software designed to simulate the behaviour of the humidity under the emitters, In addition to the difficulties in obtaining data on the hydrophysical properties of the soil, necessary for running the model, technical difficulties prevail in defining important parameters necessary to carry out the appropriate agronomic dimensioning of the irrigation system.

Analysis of the results

With regard to the wetting radius of dripper (Re), according to Arapa (2002) the value obtained is 0.39 m, higher than that obtained in variant 2. The first is less reliable than the second, since the calculation of this parameter was made from 1, which takes into account the soil texture for a flow rate in this case = 4 L/h, it should be clarified that the soil texture is hardly a constant parameter throughout the plot, in the best case it could be assured that it should be occupies a greater proportion within the same, therefore, that within a plot the soil texture can vary, as well as the discharge of the emitter.

In the second variant, the value of the wetting radius is obtained from an experimental model carried out through several field tests in certain periods of time where the behaviour of the vertical and horizontal movement of water in the wet bulb is evaluated in certain soil textures and certain flow rates, which allows obtaining a much more reliable value, and offers the possibility of making the design foreseeing a separation between emitters, different between the different irrigation plots.

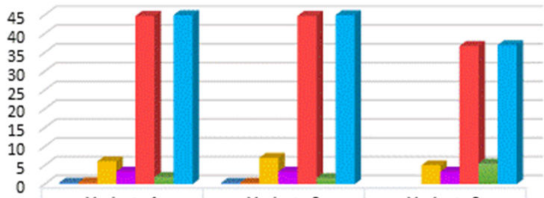
The third procedure does not take into account the wetting radius of the emitter, which introduces an inaccuracy in the results, making the pre-established emitter spacing (Se) unreliable. By not taking into account (Re), the volume or surface area wetted under the emitter remains an unknown during the design, taking the risk of the wetted strip being misplaced in relation to the root of the plants, because it is too deep (causing losses) or too shallow (failing to wet a certain number of roots which may be the most active in the crop), weakening the anchorage of the plants.

Therefore, not taking into account the radius of the emitter leads to obtaining an unreliable value of the total or definitive dose. Another element, which corroborates the above, is the fact that the distance between emitters is set at 60 cm without taking into account all the parameters involved in the shape and dimensions of the wet bulb generated under the emitters.

To determine the wetted surface area per emitter, the volume of wetted soil beneath the emitter must be taken into account, a parameter that is very difficult to obtain unless it is estimated experimentally, which has already been found to be impractical for design purposes; to overcome this difficulty, the term wetted area by the emitter was introduced, which is less accurate but easier to obtain Pizarro (1996).

However, the values obtained by taking into account the wetted surface area are more valid the more rigorous the field tests are. The field test procedure documented by Pizarro (1996) and other authors such as (Rodrigo,1997) and followed by Arapa (2002) takes into account the wetted surface area as a function of two conditions, the flow rate of the emitter and the soil texture, and through this a diameter is defined. In contrast, Cruz-Bautista *et al.* (2015) states that the wetted surface under an emitter depends on parameters such as: the amount of silt, the hydraulic conductivity of the soil, the irrigation time, the duration of the field tests and the flow rate of the emitter; therefore, the value obtained by Cruz-Bautista *et al.* (2015) despite referring to the wetted surface and not the volume, is more accurate because it takes into account more parameters that consider the horizontal and vertical displacement of the wet bulb under the emitters.

In the alternative procedure, no field test results are taken into account and no experimental or other model is available, making it impossible to obtain the radius of the emitter and thus to obtain the surface



	Variante 1	Variante 2	Variante 3
Radio de humedecimiento. [Re (m)]	0,39	0,35	
Superficie humedecida. [Ae (m2)]	0,478	0,384	
Número de goteros por plantas. [e (u)]	6	7	5
Necesidades netas. [NN (mm/d)]	3,3	3,3	3,3
Necesidades totales. NT (L/d/p)	44,68	44,68	36,69
Tiempo de riego. TR (h)	1,87	1,6	5,45
Dosis de riego. DR (L)	44,88	44,88	36,91

FIGURE 2. Results of the agronomic design of the three variants.

area wetted by the dripper. In the technical task that provides information on the case study, it is imposed that the emitters are separated at a distance (Se = 0.6m) along the lateral with an unknown criterion; if it is assumed that under this condition the overlap between the bulbs is greater than 30%, it does not necessarily imply that more water is applied to the crop, this could cause losses due to deep percolation, especially when the irrigation time is obtained from an arithmetic analysis, as is the case.

The number of emitters per plant depends on the depth of the bulb, the planting frame and the area wetted by the emitter, which must guarantee an overlap of 15-30% of the wetting radius, and also depends on the minimum wetting percentage (PHMIN). This last parameter is key to satisfy the water needs of the plant for its correct growth and development, which shows that the alternative procedure is not very convincing.

This procedure does not take this aspect into account; the number of emitters used in this procedure is obtained by dividing the total flow rate necessary to apply to the row of plants by the flow rate of the emitter, while taking into account the time necessary to apply this volume of water; this number of emitters is subject to a separation between emitters, which in this case is provided by the Technical Task. Therefore, the results obtained will not be as reliable as those proposed by Arapa (2002) and to a greater extent by Cruz-Bautista *et al.* (2015), which take into account the minimum wetting percentage.

The area of the planting frame is a fundamental aspect taken into account by these authors, related to the vital area of the crop. There is a relationship between the shade caused by the crop when it receives sunlight, which conditions the consumption of the crop (dry area and wet area), (shaded area and less shaded area), evaporation and transpiration of the crop, all of these elements influence the amount of emitters that a plant needs.

In the case of the net requirements, the same equation is used in all three variants; the data provided by the technical task were used to estimate the values.

With regard to the total requirements, practice has shown that, in several cases, difficulties in accessing data indicative of salt contents in the irrigation water or in the aqueous extract of the soil, lead to using as the sole criterion the increase of (Nn) by a fraction equivalent to the irrigation efficiency in order to anticipate possible water losses through deep percolation.

Although the values of water quality and soil quality were assumed by taking irrigation water of medium salinity, anticipating a level of salinity in the soil, this criterion is more rigorous than percolation losses, especially in high frequency irrigation systems, i.e. the presence of salinity in the aqueous extract of the soil is easier than deep percolation losses; in the alternative procedure an unknown criterion is assumed to determine the losses, but the flushing needs are not taken into account. In the method used by Arapa (2002) and Cruz-Bautista *et al.* (2015), the calculation of total requirements was done by (4.1), the electrical conductivity of irrigation water (ECar) and the soil saturation extract (ECes) were taken into account.

The irrigation time TR is one of the most defining parameters in the agronomic design of the installation, its value was very similar in the first two variants, the difference is due to the fact that in the first variant one emitter per plant is needed less than in variant 2, this is because the surface area wetted by the emitter obtained by means of (1) was greater than that obtained from the result of the experiences of Cruz-Batista and collaborators/2005; this characteristic supports the first conclusion of this work.

In relation to the third variant, the duration of irrigation was significantly higher, the procedure to obtain it was different; starting from knowing NT, the water needs in the whole row are obtained, then, starting from knowing the flow rate of an emitter and the number of these located along the lateral pipe, the duration of irrigation is increased until the volume of water applied on the row of plants coincides with the volume needed for all the plants located in the row.

As the calculation of NT in this variant did not take into account the washing needs, its value was lower than that obtained in the first two variants, and therefore the number of emitters per plant corresponding to the row was also lower; therefore, the duration of irrigation will be significantly longer in the third variant. This implies a more expensive installation in relation to the cost of pumping and less reliable agronomically by delivering a lower irrigation dose than variants 1 and 2.

CONCLUSIONS

The procedure proposed by Arapa/2002 is valid only for an emitter flow rate = 4 L/h, although it is a value frequently used in drip irrigation practice, it does not consider other values of emitter discharge, nor the duration of the test, nor the vertical advance of the moisture under the emitter.

None of the three variants take into account the moisture content or the tension at which moisture is retained in the wetted zone below the emitters. This parameter is an important element to consider during the agronomic design, as it ensures an appropriate moisture transfer to the plants.

Setting a spacing between emitters along the side without taking into account the shape and dimensions of the wet bulb generated under the emitter does not guarantee that an appropriate surface area for the crop will be wetted, nor does it guarantee that a continuous wetting strip will be generated that will lead to the best moisture transfer for the plants.

The results highlight that the experience developed by Cruz-Batista et al./2015, demonstrate the validity of the experimental models built through field tests for use as reliable tools for the agronomic design of drip irrigation installations.

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