

IRRIGATION DIMENSIONING OF REEL MACHINES WITH WATER DISTRIBUTION SYSTEMS: GUN AND BOOM WITH EMITTERS

DIMENSIONAMIENTO DEL RIEGO DE ENROLLADORES CON SISTEMAS DE DISTRIBUCION DE AGUA: CAÑÓN Y RAMAL CON EMISORES

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ABSTRACT

The reel machines irrigation technique has expanded in recent years thanks to the technological improvements that have been introduced. Several investigations have been carried out regarding the effectiveness of the irrigation of this equipment with “gun” type water distribution systems, but very few about the “boom with emitters”. This includes methodological or calculation procedures for dimensioning irrigation in an agricultural area. Therefore, the objective of this work is *to establish a comprehensive methodology for the correct dimensioning of irrigation by reel machines with water distribution systems of the “gun” and “boom with emitters” type*. Agronomic design is addressed as a fundamental part, and hydraulic design up to the necessary pressure in the hydrant. The relevant aspects in this procedure are that, formulations are included for the dimensioning of irrigation with water distribution systems of the “boom with emitters” type, and that correct values and criteria are used to support the methodology, because these come from authors and institutions of international prestige.

Keywords: reel machines, gun, boom with emitters, water distribution, irrigation dimensioning.

RESUMEN

La técnica de riego por enrolladores se ha expandido en los últimos años gracias a las mejoras tecnológicas que se le han introducido. Se han realizado varias investigaciones en cuanto a la efectividad del riego de estos equipos con sistemas de distribución de agua del tipo “cañón”, pero muy pocas sobre los “ramales con emisores”. Esto incluye los procedimientos metodológicos o de cálculo para el dimensionamiento del riego en un área agrícola. Por lo que el objetivo de este trabajo es *establecer una metodología integral para el correcto dimensionamiento del riego por enrolladores con sistemas de distribución de agua del tipo “cañón” y “ramal con emisores”*. Se aborda el diseño agronómico como parte fundamental, y el diseño hidráulico hasta la presión necesaria en el hidrante. Los aspectos relevantes en este procedimiento son que, se incluyen formulaciones para el dimensionamiento del riego con sistemas de distribución de agua del tipo “ramal con emisores”, y que se utilizan valores y criterios acertados para soportar la metodología, ya que provienen de autores e instituciones de prestigio internacional.

Palabras clave: enrolladores, cañón, ramal con emisores, distribución de agua, dimensionamiento del riego.

INTRODUCTION

According to González (2003), the reel irrigation technique has led to a great expansion of its use in the world. These equipments have evolved over the years, expanding their use in terrain with considerable slopes, in addition to achieving a high use of hydraulic energy, due to new generations of sprinklers and booms with emitters, and also to the design of more efficient turbines (Allen et al., 2000; Uribe et al., 2001).

On the other hand, Jiménez et al. (2015) stated that in the irrigation with reels machines, there is a boom with emitters modality (ala piovana), for the irrigation of small crops that has the advantage that, during its operation, it requires low working pressure. However, what undermines this sprinkle irrigation technique is the high intensity of application, restricting its use to soils with high infiltration rates. Said author raised another problem where the overlapping percentages established for the design of this equipment with traveling sprinklers are inadequate where there are high wind speeds, as well as prevailing transverse and diagonal wind directions with respect to the movement of the sprinkler.

As in all irrigation techniques, there are methodologies for dimensioning irrigation in traveling irrigation machines (reels machines). For example, NRCS (2005) establishes some considerations for the correct design of traveling sprinklers. Sánchez et al (2015), proposed a methodology for the irrigation management in sugar cane where he establishes a series of formulations associated with traveling irrigation guns. Rolim and Teixeira (2016) propose a software with their methodological support for the design and evaluation of irrigation systems with traveling gun. Tarjuelo (2005), also developed a procedure for irrigation design with this type of water distribution system.

However, the established methodologies do not address specific aspects of reel machines with “boom with emitters” type water distribution systems. Some authors and institutions such as Tarjuelo (2005) and NRCS (2005) only refer to general aspects of these devices.

Based on the foregoing, the goal of this work is to establish a comprehensive methodology for the correct dimensioning of irrigation by reels machines with water distribution systems of the “gun” and “boom with emitters” type.

CALCULATION PROCEDURE

Agronomic design

The first step is to obtain information about crop water requirement (N) in its period of greatest demand (in mm or L/m^2). Then the partial net irrigation depth is determined with the following universal formula for the calculation of any irrigation system:

$$Dn = 10 \cdot bd \cdot H \cdot (Fc - Wp) \quad (1)$$

where Dn : partial net irrigation depth in mm; bd : bulk density in g/cm^3 ; H : roots effective depth in cm; Fc : field capacity in cm^3/cm^3 and Wp : wilting point in cm^3/cm^3

The physical properties of the soils can be obtained from local research data or values estimated by various authors such as Hansen et al. (1980) shown in Table 1. The formulations developed by Saxton et al. (1986) can also be used in the case where local soil texture data are available.

Table 1. Physical properties of soils according to texture.

Texture	Porosity (%)	Bulk Density (g/cm^3)	Field Capacity (pds)	Wilting Point (pds)
S	38	1.65	9	4
SL	43	1.5	14	6
L	47	1.4	22	10
CL	49	1.33	27	13
SC	51	1.3	31	15
C	53	1.25	36	17
pds- percent dry soil S- Sand SL- Sandy Loam L- Loam			CL- Clay Loam SC- Sandy Clay C- Clay	

The irrigation frequency is calculated as the ratio between the partial net irrigation depth (Dn) and the crop water requirements (N).

$$I_f = \frac{Dn}{N} \quad (2)$$

where I_f : irrigation frequency (dimensionless)

Decimal values of the irrigation frequency are generally obtained. But in practice it is convenient to irrigate with days of entire intervals. Therefore, the I_f value is approached to an integer value and equation (2) is solved for:

$$Dn_a = N \cdot I_{fe} \quad (3)$$

where Dn_a : adjusted partial net irrigation depth in mm and I_{fe} : irrigation frequency (entire value)

Then the gross irrigation depth is calculated:

$$Db = \frac{Dn_a}{Ea} \quad (4)$$

where Db : gross irrigation depth in mm and Ea : application efficiency

There is an extensive specialized literature where application efficiency values for this irrigation technique are provided. The following information is shown below (Table 2).

Table 2. Application efficiency values for traveling irrigation machines.

Denomination	Ea(%)	Source
Traveling sprinklers (gun type or boom)	55-65	NRCS (2005)
Travelling sprinkler (gun type)	65-77	Keller (1990)
Gun (drawn by reel or cable)	55-70	Santos et al (2010)

If there is information from field evaluations, the equation proposed by Walker (1979), quoted by USDA-SCS (1993), can be used.

$$Ea = [1 - (1.25 - 0.0125 \cdot CU)(3.634 - 1.123 \cdot A_u^{0.3} + 0.003 \cdot A_u^{1.233})] \quad (5)$$

where Ea : application efficiency (%); A_u : fraction of the field that is deficitly irrigated and CU : coefficient of uniformity.

To determine the flow of the irrigation system the formula is used (Tarjuelo, 2005):

$$Q = \frac{(3.6 \cdot N \cdot A)}{(Ea \cdot Trd)} \quad (6)$$

where Q : flow of irrigation system in L/s; A : area to irrigate in ha and Trd : hours of system operation in h/day.

Therefore, the water supply rate is calculated as:

$$q = \frac{Q}{A} \quad (7)$$

where q : water supply rate in L/(s.ha).

Application rate is an important design parameter, because the infiltration capacity of the soil must be ensured. Therefore, the selection of the sprinkler is correct when the application rate of the rain is below the infiltration rate. In the case of irrigation guns, it is determined as follows:

$$I = \frac{Q_E}{A_S} \quad (8)$$

where I : application rate in mm/h; Q_E : flow of reel machine in L/h and A_S : circular sector area in m^2 .

$$A_S = \pi \cdot (0.9 \cdot R_c)^2 \cdot \frac{\alpha}{360} \quad (9)$$

where α : gun irrigation angle in degrees and R_c : gun irrigation radius in m

Application rate in boom with emitters is high and its use is limited to soils with a higher infiltration rate. Tarjuelo (2005), states that these water distribution systems must be well dimensioned, otherwise the irrigation depth would have to be applied on more than one route and would make the operation more expensive. On the other hand, Jiménez et al (2015), obtained considerably high application rates values and proposed that booms be developed with emitters of greater wetting width. In this case it is determined as:

$$I = \frac{Q_E}{(A_m \cdot F_m)} \quad (10)$$

where A_m : wet width of emitters in m and F_m : wet width by the boom with emitters in m.

The space between irrigation settings for the guns is calculated:

$$E = 2 \cdot R_c \cdot \frac{P_{DM}}{100} \quad (11)$$

where E : space between irrigation settings in m and P_{DM} : wet diameter percent.

Table 3 shows the spacing values in percent of the wet diameter for jet path angles of 23° to 25°.

Table 3. Recommended spacing between strips according to wind speed. (Keller and Bliesner, 1990)

Wind speed interval (km/h)	Spacing as % of the wet diameter
0 to 3.5	90
3.5 to 8	80 to 85
8 to 16	70 to 75
>16	60 to 65

About booms with emitters it is different because a rain curtain is generated. Therefore, the equation is as follows:

$$E = L_A \quad (12)$$

where L_A : boom length in m.

However, there are booms with sprinklers, where the last emitters on both sides have a considerable wetting radius. It must be considerate:

$$E = L_A + (2 \cdot R_{DE} \cdot \frac{P_{DME}}{100}) \quad (13)$$

where P_{DME} : wet diameter percent of the end sprinklers of the boom; L_A : boom length in m and R_{DE} : radius irrigation of the emitters of both tips in m.

$$R_{DE} = \frac{(F_m - L_A)}{2} \quad (14)$$

Table 3 can be used to define the P_{DME} value, and the values of F_m and L_A are obtained from the supplier's catalogs.

To define the number of strips to irrigate, the layout defined in the project is analyzed and the lengths of the straight sections of the pipe with hydrants are added to apply the following formula:

$$B = \frac{L_c}{E} \quad (15)$$

where B : number of strips to irrigate and L_c : length of the pipe with hydrants in m.

It also frequently happens that a decimal value of the number of strips to be irrigated is obtained. In this case, it approaches an integer value and the space

between irrigation settings is determined again, obtaining:

$$E_A = \frac{L_c}{B_R} \quad (16)$$

where E_A : adjusted space between irrigation settings, in m and B_R : number of strips to irrigate approximate to integer value.

The retraction speed of both the gun and the boom with emitters is determined by the following expression:

$$V = \frac{Q_E}{D_b \cdot E_A} \quad (17)$$

where V : retraction speed in m/h.

Equations 18, 19 and 20 are applicable only to traveling gun irrigation:

$$D_i = \frac{2}{3} \cdot R_c \quad (18)$$

where D_i : distance to the edge of the area to start irrigation, in m.

$$T_i = \frac{2}{3} \cdot \frac{\alpha}{360} \cdot \frac{R_c}{V} \quad (19)$$

where T_i : gun irrigation time without moving to the end of the strip, in min.

$$T_f = \frac{2}{3} \cdot \left(1 - \frac{\alpha}{360}\right) \cdot \frac{R_c}{V} \quad (20)$$

where T_f : gun irrigation time without moving at the beginning of the strip, in min.

To determine the time it takes for the reel machine to irrigate the strip, if the area has regular dimensions, it is determined by the following expression:

$$T_{RB} = \frac{L_B}{V} \quad (21)$$

where T_{RB} : time it takes for the reel machine to irrigate the strip, in h and L_B : strip length in m.

In the case of an irregular area, the lengths of all the strips are added together and divided by the number of strips in the area to obtain L_{BP} , obtaining:

$$T_{RB} = \frac{L_{BP}}{V} \quad (22)$$

where L_{BP} : average length of the strips in m.

So the number of strips to irrigate in a day would be:

$$N_B = \frac{T_{rd}}{T_{RB} + T_c} \quad (23)$$

where N_B : number of strip to irrigate in a day and T_c : change time between irrigation settings in h.

If it is considered that the reel machine must make the complete journey in the strip, the value of N_B must be an almost integer or integer number, otherwise the selection of the irrigation equipment must be proceeded to achieve this purpose. But if the reel machines can stay in the field without finishing its journey in the strip, the calculations continue.

To obtain the necessary flow at the pumping station, proceed with the following formulations:

$$A_{EI} = V \cdot T_{rd} E_A \cdot I_r \quad (24)$$

where A_{EI} : area irrigated by the reel machine in the irrigation frequency in ha.

$$C_E = \frac{A}{A_{EI}} \quad (25)$$

where C_E : number of reel machines in the area

$$Q_{EB} = Q_E \cdot C_E \quad (26)$$

where Q_{EB} : necessary flow at the pumping station in L/s.

Generally the Q_{EB} value differs from the Q value due to the adjustments that are made in the calculation process. Therefore, the Q_{EB} value is the one that will be used for the hydraulic design of the network.

Hydraulic Design

To determine the necessary pressure in hydrant output, suppliers offer technical, hydraulic and operational characteristics of their equipment, which

facilitate the design process of the irrigation system. However, the necessary parameters in the hydraulic calculation according to Tarjuelo (2005) are provided below.

$$P_E = P_e + \Delta h + h_m + h_e + h_t + h_s \quad (27)$$

where P_e : pressure in the gun or boom with emitters in m.c.a.; Δh : difference in terrain altitude in the direction of the hose in m (obtained from topographic information) and h_m : pressure loss in the hose in m.c.a.

$$h_m = (10.64 + C^{-1.85} + D^{-4.87} + Q_E^{1.85}) \cdot L_m \quad (28)$$

L_m : hose length in m; C : material coefficient; D : diameter inside the hose in m; Q_E : flow of reel machine in m³/s; h_e : height of gun or boom with emitters in m; h_t : pressure loss inside turbine in m.c.a. and h_s : pressure losses in other components in m.c.a.

CONCLUSIONS

The calculation procedure for irrigation systems with traveling guns and traveling booms with emitters has been established, the latter being the most relevant water distribution system because there is little information regarding formulations for its dimensioning in agricultural areas.

Reliable criteria and indicator values were shown to support this methodology, because this information comes from internationally recognized authors and institutions.

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