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METHODOLOGY FOR DIMENSIONING OF A CENTER PIVOT IRRIGATION SYSTEM OPERATING WITH DRIPPER TYPE EMITTER

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ALEX N. DE ALMEIDA[1*], RUBENS D. COELHO[2], JÉFFERSON DE O. COSTA[2], ASDRÚBAL J. FARÍAS[2]

[1*] Corresponding author. Escola Superior de Agricultura "Luiz de Queiroz" - ESALQ/ Universidade de São Paulo - USP/ Piracicaba - SP, Brasil. E-mail: alexn@usp.br

ABSTRACT: In Brazil, the conventional center pivot is widely used for irrigation of agricultural crops and its use has grown continuously. However, when improperly managed, it facilitates the development of diseases in all parts of the plant, with a direct effect on productivity, besides favoring losses of water by evaporation. The drip may be an alternative, since it minimizes the losses and does not wet the aerial parts of the plants, thereby reducing the incidence of diseases. A new system called localized mobile drip irrigation (IRGMO) is being developed in an attempt to combine the practicality and rusticity of the center pivot with the efficiency and water savings of the dripping irrigation systems. This fusion system is the central pivot with drip irrigation system for water distribution in the soil surface. This study aims to present a calculation methodology for the design of IRGMO system and compare it with conventional systems. It is concluded that this methodology allows the design of the IRGMO and that this new technology allows a savings of approximately 99% in a number of drip tubes compared to the conventional system with fixed drip irrigation lines in the field.

KEYWORDS: design, drip irrigation, center pivot.

INTRODUCTION

The estimated growth of the irrigated area in the world in the coming years is about 180 million hectares, added to the area currently under irrigation of 304 million hectares, will result in a total of approximately 484 million hectares irrigated in the future. This estimate considers the possibility of incorporation of the Brazilian sustainable development potential areas of irrigated agriculture, representing an additional to the currently irrigated area of approximately 25 million hectares, that is, Brazil has a potential of approximately 14% of the global capabilities of incorporation of new areas for irrigated agriculture (Christofidis, 2013).

The more irrigation methods used in Brazil are the traditional sprinkler and semi-mechanized (conventional e auto-propelled) with 35% of the irrigated area, mechanized center pivot sprinkler (19%), localized (8%), by surface (6%) and others (8%) (Paulino et al., 2011).

Several irrigation systems can be used to meet the water demand of a particular culture in the field; however, to choose the system it is necessary to consider several factors such as soil type, topography, water supply etc. Some irrigation systems, such as center pivot and conventional spraying, when handled inappropriately provide leaf diseases and fruit rot, in addition to promoting evaporative water loss by water retention in the canopy of plants. An alternative sprinkler system is the drip, which minimizes the loss of water by evaporation allowing the distribution of water for plants, and in the desired amount, moreover, there is the immersion of the aerial part of plants, and contributes to the reduction of the incidence of weeds (Oliveira et al., 2014).

Vicente et al. (2011), determined the uniformity of application of 27 central pivot irrigation systems, located in three municipalities in the region West of Bahia (Brazil) and concluded that the

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[2] Escola Superior de Agricultura "Luiz de Queiroz" - ESALQ/ Universidade de São Paulo - USP/ Piracicaba - SP, Brasil.

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central pivots in the application of type LEPA (low energy precision application) showed values of uniformity superior to conventional central pivots.

Climatic conditions also have a significant effect on the efficiency of sprinkler irrigation. Strong winds can cause conditions of low distribution uniformity. In addition, in arid and semi-arid areas, the center pivot systems feature a greater amount of evaporation than in other climates, thus improving the efficiency of this system is something desirable (Derbala, 2003).

Currently, one of the most suitable systems and remarkable expansion is the drip irrigation system, which presents some advantages, being water and energy savings the most cited, facing the situation of water availability and the price of electric energy (Ribeiro et al., 2010).

One of the problems that the drip irrigation system offers is the possibility of clogging of emitters in the field, due to the low flow drippers (0.6 to 3.5 L h^{-1}), necessary for the economic viability of the system, which is one of the biggest impediments to applications and popularization of this technology (Li et al., 2012).

One of the causes of clogging include physical, chemical and biological factors (Asgari et al., 2012; Niu et al., 2013; Pedrero et al., 2010). Hydraulic factors can also contribute in the process of clogging in the field like the inlet pressure, the flow and the speed of water circulation within the system (Capra & Scicolone, 2007; Li et al., 2012; Silva et al., 2012).

When they replaced the sprinklers of a pivot for polyethylene tubing with emitters to bring irrigation water to the soil surface becomes directly the mechanized sprinkling system on a system of "Mobile" drip irrigation (IRGMO) or "Precision Mobile Drip Irrigation" (PMDI). The IRGMO system combines the advantages of the steady drip irrigation, such as low-pressure requirements and low evaporative losses, with the advantages of the pivot, which has cost smaller deployment than the drip irrigation. The replacement of the pivot sprinklers by drippers can reduce power consumption by up to 70% and up to 20% water (Hezarjaribi & Sourell, 2011; Derbala, 2003).

In addition, the IRGMO systems feature smaller problems of clogging of emitters, since they enable economically with higher flows of drippers. Faria (2013) comments that emitters with flow between 1.0 to 1.7 L h^{-1} are more susceptible to clogging by particles in suspension than emitters with flow between 2.0 to 3.5 L h^{-1}. Thus, a way to control this phenomenon consists in working with the larger flows with possible bigger pressures in drip irrigation systems.

On the above, the objective of the present study was to develop a methodology of calculation of design an IRGMO system, making conventional pivots sizing simulations and comparisons with localized irrigation systems drip type.

DESCRIPTION OF THE SIZING METHODOLOGY

As the IRGMO system was developed by replacing the pivot sprinklers, it was used in the calculations of this system sizing the data necessary for the design of a pivot, which are: the water infiltration in the soil, the size of the area to irrigate, the spacing between emitters, the efficiency of the system, the daily operating time, and the time of a full turn.

In addition, data were used for the adjustment of the evapotranspiration from the dimensioning of irrigation systems, such as evapotranspiration rate of the culture, wet area by the emitter, the shaded area by the plant, the total area of the plant, and the emitter spacing.

Input variables

In the designer of the IRGMO are necessary input data for the initial calculations can be performed. These parameters that will be used in the following equations are described in Table 1.

For the better understanding of the parameters related to the designer of IRGMO systems Figure 1 is shown then.

TABLE 1. Description and acronyms of the parameters required for the design of the IRGMO.

Variable	Acronym
Distance to the last Tower (m)	DUT
Swing length (m)	CB
Distance between exits of hose (m)	DSM
Wet track width of the emitter (m)	LFM
Evapotranspiration of culture (mm day^{-1})	ETc
Total area of the plant (m^2)	ATP
Shaded area for plant (m^2)	ASP
Wet area by the emitter (m^2)	AMe
Efficiency of the system (%)	EAS
Daily operating time (h)	TOD
Time of a full turn with the relay 100% (h)	TVC
1 term of the curve of infiltration (soil-dependent constant)*	T1
2 term of the curve of infiltration (exponent)*	T2
The emitter flow drip line (L h^{-1})	Qemi
Spacing between drip emitters (m)	Emi

* According to the model of Kostiakov (1932).

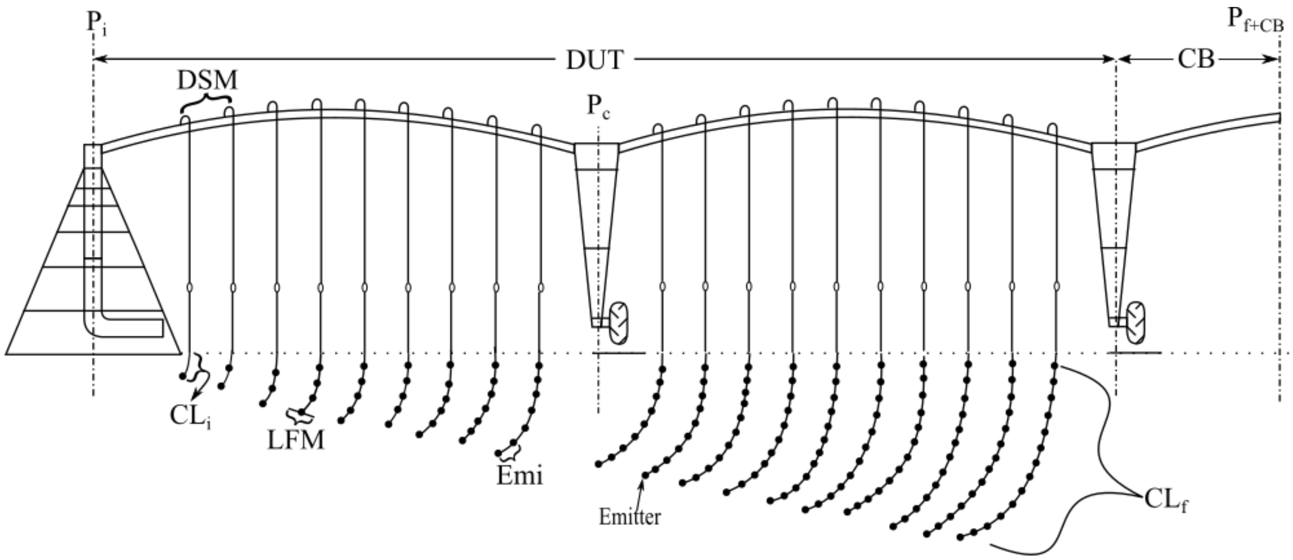

FIGURE 1. Schema of an IRGMO system. P_i– initial point; P_c – central point of the pivot; P_f-CB – final point of the pivot with balance sheet; DUT – distance to the last tower; CB – length of the balance sheet; DSM – distance between exits of hose; CL_i – dripper tube length of the first line; CL_f– dripper tube length of last line; LFM – width of the wet track by the emitter; Emi – emitter spacing in the dripline.

Calculations performed

The distance to the last exit for the hose is calculated by the sum of the distance to the last Tower (DUT) and the swing length (CB).

$$DUS = DUT + CB \tag{1}$$

on what,

DUS – distance to the last exit for hose, m.

The number of lines is calculated by the ratio of the distance to the last exit for hose (DUS) and the distance between exits of hose (DSM).

$$NL = \frac{DUS}{DSM} \tag{2}$$

on what,

NL – number of lines, dimensionless;

According to Mantovani et al. (2009) must consider two important concepts in the sizing of this type of system, which is the percentage of the area shaded by the plant (PAS) and the percentage of wet area (PAM).

The first concept expresses the ratio between the shaded are for the plant (ASP) and the total area occupied by this same plant (ATP):

$$PAS = \frac{ASP}{ATP} 100 \tag{3}$$

on what,

PAS – percentage of shaded area, %.

The second, expresses the percentage of wet area, in relation to the total area occupied by the plant, and depends on the emitters (flow, spacing and irrigated radius) and plant characteristics (spacing and development):

$$PAM = \frac{AMe}{ATP} 100 \tag{4}$$

on what,

PAM – percentage of wet area, %; e

AMe – wet area by the emitter, m².

According to Mantovani et al. (2009), based on PAS and PAM, make necessary a correction which reduces the evapotranspiration of culture (ETc), by reducing the direct evaporation from the soil of the area wet. Despite the complexity of the process, in simplified form, the evapotranspiration set can be represented by the following equation:

$$ETcA = ETc\ K_L \tag{5}$$

on what,

ETcA – evapotranspiration of culture adjusted, mm dia^{-1}, and

K_L – correction factor due to location, depending on the stage of development of culture, the spacing, the wet area and shaded area, dimensionless.

To define the values of KL, there are several methodologies, in this study was considered the method proposed by Keller & Bliesner (1990):

$$K_L = (Pmax^{0,5})\ 0,1 \tag{6}$$

on what,

Pmax - the greater value between PAS and PAM, %.

The irrigated area is calculated based on the distance to the last exit for hose, as the [eq. (7)]:

$$ARR = \frac{\pi\ DUS^2}{10000} \tag{7}$$

on what,

ARR – irrigated area, ha.

According to Bernardo et al. (2006), the speed of the center pivot with the relay 100% is calculated based on the distance to the last tower and a full turn with the relay 100% (TVC) as [eq. (8)]:

$$VPR = \frac{2\,\pi\,DUT}{TVC} \tag{8}$$

on what,

VPR – pivot speed with the 100% relay, m h^{-1}.

The flow of the central pivot is calculated according to [eq. (9)]:

$$QP = \frac{[ETcA\;TOD]ARR}{TOD\;\left(\frac{EAS}{100}\right)} \tag{9}$$

on what,

QP – pivot central flow, $m^3\ h^{-1}$;

TOD – daily operating time, h, and

EAS - efficiency of the system, %.

According to Bernardo et al. (2006), the average intensity of application (Iavg) is given by the following equation:

$$Iavg = \frac{Q_{emi}}{E_{emi} \cdot LFM} \tag{10}$$

on what,

Iavg – average intensity of application, mm h^{-1};

Q_{emi} - the emitter flow drip line, L h^{-1}, and

LFM – wet track width of the emitter, m.

The maximum intensity of application (Imax) is given by [eq. (11)]:

$$Imax = 1.05\ Iavg \tag{11}$$

on what,

Imax – maximum intensity of application, mm h^{-1}.

The effective range (We) is calculated by the ratio between the average intensity (Iavg) and the maximum intensity of application (Imax) multiplied by the distance between exits of hose (DSM) (Bernardo et al., 2006).

$$We = \frac{Iavg}{Imax}\ DSM \tag{12}$$

on what,

We – effective range of the transmitter, m.

The critical time is calculated using [eq. (13)]:

$$TC = \left(\frac{Imax}{T1}\right)^{\frac{1}{T2}} \tag{13}$$

on what,

TC – time critical, h;

T1 – 1 term of the curve of infiltration (soil-dependent constant), dimensionless, and

T2 – term of the curve of infiltration (exponent), dimensionless.

According to Mantovani et al. (2009), the theoretical flow drip line (Qteo) is given by the [eq. (14)]:

$$Qteo = \frac{QP\ 2\ LFM\ R_i}{DUS^2\ 1000} \tag{14}$$

on what,

Qteo – theoretical flow drip line, L h^{-1}, and

Ri – distance between the center of the pivot and drip line, m.

The number of emitters (NeTe) is calculated by the ratio between the theoretical flow drip line (Qteo) and the flow of the emitter (Qemi).

$$NeTe = \left\lceil \frac{Qteo}{Qemi} \right\rceil \tag{15}$$

on what,

NeTe – number of theoretical emitters, (set to an upper integer).

As the number of emitters (NR) must be an integer that value has been set up, namely, the next higher whole number that found as [eq. (16)]:

$$NR = NeTe \tag{16}$$

on what,

NR – number of actual emitters, dimensionless.

The actual flow (QR) is calculated due to the adjustment that is made in the number of emitters (NR).

$$QR = Qemi\ NR \tag{17}$$

on what,

QR – real flow applied on line, L h^{-1}.

Finally, the length of the drip line (LDL) is calculated by multiplying the number of emitters and the spacing between emitters, according to [eq. (18)].

$$LDL = NR\ E_{emi} \tag{18}$$

on what,

LDL – Length of the drip line, m.

14 to 18 equations are applied in a timely, i.e. are applied line by line, this is necessary due to the fact that the flow of each line is directly linked to the distance from the central part of the equipment (pivot base).

In Figure 2 can be seen a diagram that illustrates a simplified form the methodology of the IRGMO. The input data (components of culture, pivot and issuing data) are at the top of the diagram, then you must define the way of obtaining the maximum length of the line and finally the IRGMO. The variable "Cmax" reported in Figure 2 refers to the maximum length of the drip line, respect the permissible operating pressure variation on the dripline, the methodology for this calculation follows the standard covered by Frizzone et al. (2012). In such a way that the user has two choices, calculate the system without this restriction (and there is the possibility to have very long lines) or calculate the maximum length restriction, in this case the user sets a maximum length value in hydraulic constraints to function for calculating the dripline, which can be further limited by a lower maximum length for operational readiness of equipment in the field.

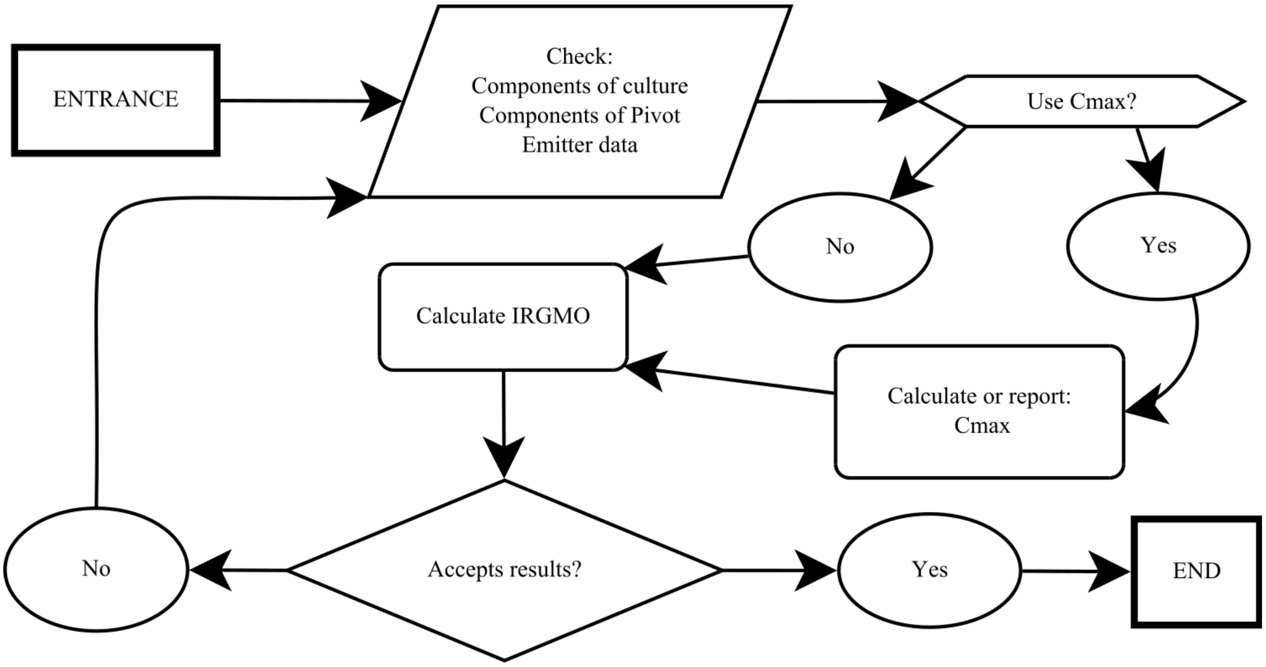

FIGURE 2. Diagram of the methodology for the design of IRGMO.

Simulations were carried out IRGMO sizing in three centers of various sizes. For all these pivots considered: distance between hose exits of 3 m, evapotranspiration of culture of 4.75 mm day^{-1}, wet track width emitter of 1 m, daily operating time of 21 hours, time of a full turn with the relay 100% of 24 hours and efficiency of the system of 90%. In relation to the emitters drip used with a flow rate of 12 L h^{-1} with a spacing of 0.4 m. A summary of the data used in the simulations can be seen in Table 2.

TABLE 2. Parameters used in the simulations.

Variable	Pivot 1	Pivot 2	Pivot 3
Size of the pivot, without balance (DUS), m;	100	200	400
Number of lines (NL);	33	66	133
Irrigated area (ARR), ha;	3.14	12.57	50.27
Pivot speed with the 100% relay (VPR), m h^{-1};	26.18	52.36	104.72
Theoretical flow of all pivot (Qteo), m³ h^{-1};	2.66	10.47	42.21
Average intensity of application (Iavg), mm h^{-1};	52.12	103.98	207.70
Maximum intensity of application (Imax), mm h^{-1};	66.36	132.39	264.45

The simulations carried out in this study aim to validate the methodology described for IRGMO system sizing and demonstrate through situations created by authors such as would be the maximum length of each dripline and their corresponding flow, thus allowing a comparison with irrigation systems in conventional drip.

So, remember, that to perform other types of comparisons, such as those involving the durability of the transmitter (which will suffer a drag), the vulnerability to clogging in this new modality of use of dripline and the behavior of these in different situations of uniformity of application, field tests are required.

RESULTS OF SIMULATIONS

The results obtained from the simulations can be observed in the Tables 3, 4 and 5. These results are in summary form in order to have an overview of the data obtained for each simulation, since the lines with the same number of the order have the same flow rate.

It is worth mentioning some peculiarities of the methodology, such as the possibility of the estimated flow rate be greater than the flow rate calculated for the pivot, this occurs by rounding in the calculation of the number of emitters. Another peculiarity is that the methodology presents the total length of the dripline, which in certain situations may be too high. In this case, it is advisable to use more than one dripline at that point. On the methodology, for the sizing of IRGMO this situation was foreseen and the user can choose to use or not the maximum length calculated.

TABLE 3. Simulation results for pivot 1.

Nº Line	Dripline length (m)	Line flow (L h^{-1})
1	0.2	12.0
2	0.2	12.0
3	0.4	24.0
...	...	...
31	2.4	156.0
32	2.6	156.0
33	2.6	168.0

In Table 3 can be seen the results of the simulation for pivot 1. These results indicate the length of the dripline for each row and their respective flow. It is observed that in the last line the length of the calculated dripline was of 2.6 m and the flow of 168 L h^{-1}.

In the simulation for pivot 2, the results were the last line length of 5.2 m and a flow rate of 324 L h^{-1}, as Table 4.

TABLE 4. Simulation results for pivot 2.

Nº Line	Dripline length (m)	Line flow (L h^{-1})
1	0.2	12.0
2	0.2	12.0
3	0.4	24.0
...	...	...
31	2.4	156.0
32	2.6	156.0
33	2.6	168.0
...	...	...
64	5.0	312.0
65	5.2	324.0
66	5.2	324.0

In Table 5 is shown the simulation results for pivot 3 that reached a dripline length in the last row of 10.6 m and a flow rate of 636 L h^{-1}.

TABLE 5. Simulation results for the pivot 3.

Nº Line	Dripline length (m)	Line flow (L h^{-1})
1	0.2	12.0
2	0.2	12.0
3	0.4	24.0
...	...	...
65	5.0	312.0
66	5.2	324.0
67	5.2	324.0
...	...	...
131	10.4	624.0
132	10.6	636.0
133	10.6	636.0

The methodology for the sizing of IRGMO showed that if gets a dripline length and a total flow in line for every distance from the central point of the equipment for each project analyzed the situation.

It was also made a comparison of the total length of dripline required in three systems of IRGMO, calculated in previous simulations, with the conventional drip. Irrigation efficiency in conventional drip was 90% efficiencies found by Oliveira et al. (2004). In Table 6 it can be observed the length of dripline using the IRGMO system and the conventional drip.

TABLE 6. The total length of dripline using the IRGMO and conventional drip system.

Pivot	Area (ha)	IRGMO (m)	Conventional drip (m)	Relationship IRGMO / Conventional drip (%)
1	3.14	44.4	20,933.3	0.4
2	12.57	174.8	83,800.0	0.4
3	50.27	704.0	337,133.3	0.4

In the IRGMO the total length of dripline was much smaller than in conventional drip in three simulated situations. On average the dripline economy in this new system of irrigation was 99.6%, i.e. in the IRGMO system, the total length of only 0.4% of the dripline represents the total length in the conventional drip system. Another advantage of the IRGMO system that is worth highlighting is the reduced risk of emitters'clogging because the system uses high flow emitters.

CONCLUSIONS

The presented methodology allows IRGMO design in deployments of new projects and the modification of equipment already installed in the field. In addition, even though this new technology you need the support of a center-pivot type machining system, this expressive mode reduces the amount of dripline required, thus allowing a substantial economy of plastic material compared with conventional irrigation systems. The possibility of working with higher turbulent flows reduces the risk of clogging in the field, however, if this problem will occur, the cost to replace the clogged dripline is much smaller.

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