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APPLICATION OF MATHEMATIC MODELS OF WATER IN IRRIGATED BEAN CROP UNDER NO-TILLAGE SYSTEM

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ABSTRACT Irrigation quality is estimated trough mathematical models that describe the water depths distribution along its irrigated area, indicating the irrigation efficiency parameters (application efficiency, storage efficiency, depth water percolation and deficit area) on hydraulic evaluation of field systems. The objective of this research work is to determine these efficiency parameters from two mathematical models of water distribution on soil surface (linear and normal) for each bean crop stage irrigated by sprinkler irrigation, in no-tillage system with 4, 6, 8 and 12 t ha^{-1} of mulching originated from summer crop (millet) and verifying its relation with grain production. The irrigation management was carried through irrigation schedule, keeping the water content of the soil around 28% (critical moisture for the crop) and 31% (field capacity). Mathematical models analyzed indicated similar behavior between evaluated parameters for all treatments; some exceptions were noticed regarding depth water percolation. The normal mathematical model indicated higher values in relation to the linear mathematical model. Irrigation quality evaluation parameters obtained through the evaluated mathematical models demonstrated similar field conditions for this experiment based on water depths, either when in deficit or in excess of water on crop productivity. Treatments 4 and 12 t ha^{-1} indicated lower values of application efficiency, excess water and higher productivity.

Keywords: Mulching, Irrigation efficiency, Grains production.

INTRODUCTION

The same occurrence on models, used to evaluate irrigation quality based only on results of hydraulics evaluation tests of irrigation systems, describing water depths distribution along irrigated area, which is a function of their project parameters, no analyzing if these same parameters obtained for models have some relation with crop productivity or water requirements differentiated for each development stage. Therefore, this research work has proposed to analyze quality of irrigation through linear and normal mathematics models, and uniformity coefficient of distribution for each stage of bean crop irrigated by sprinkler irrigation system, on no-tillage system with different quantities of mulching provided by millet crop. Brazil is considered a potential country to increase its agricultural production and it has been reached through more rational use of production factors, objectiving a improvement of crop performance index without cause big impacts to the environment. Application efficiency on irrigated agriculture can be obtained through correct management of irrigation systems and introduction of soil and water conservation techniques, associated to the refined learning about water requirements to plants for each growing stage.

Every irrigation system has a kind of no uniformity degree in field condition, and according to Solomon (1990) and Montazar & Sadegui (2008), it affects directly the system application efficiency and crop productivity because equipments with low distribution uniformity can cause productivity reduction, as in water deficit as in over irrigation. About a situation related to water deficit, every infiltrated water is storage at root zone, but, this quantity of infiltration cannot be enough to supply water demand to the crop in a determined growing stage, compromising its production, mainly if water deficit stress occurs on period of germination, flowering and grains filling, more specifically about annual crops. About a second case, i.e., when excess of water applied occurs, besides water resources wasting, which it can also cause economic and environmental damages, when nutrients are dragged on by leakage or runoff for irrigation water depths applied excessively to get over its low distribution of irrigation system.

Irrigation performance is frequently determined through uniformity index, that express spatial variability of water depths applied, for example, the Christiansen Uniformity Coefficient (CUC), the Distribution (UD), and through two irrigation efficiency index: Applying and Storage. The application efficiency measures the water content storage on root zone in relation infiltrated water, while storage indicates water maintenance appropriated in root system effective depth (Fietz et al., 1999). These performance indicators can be obtained directly of water depth values, measured punctually in field or mathematic models, when correctly adjusted, obtain the continuous functions, possibiliting an application of area and volume calculus, which are essentials to determination of irrigation performance parameters (Silva et al., 2004).

According to Silva et al. (2004) several mathematic models has been proposed to describe distribution of water depths applied for different irrigation system, among them, linear, normal, beta, gama, potential, etc. According theses authors, Walker (1974) applied normal model on evaluation of sprinkler irrigation system, which uses the standardized normal distribution described previously.

Linear model was developed by Karmeli (1978), and according to Souza & Ribeiro (1984) apud. (Fietz et al., 1999) relates the frequency curve of water depth accumulated and fraction of irrigated area through linear regression, expressing mathematically the uniformity and efficiency as function of water depth applied on soil surface and medium water depth applied on root zone. The beta model distribution demonstrated by Elliot et al. (1980) has good flexibility to describe several varieties of water distribution profile to sprinkle irrigation. The gama model, applied by Chaudry (1978) to varieties of asymmetrical distribution profile to different kinds of irrigation systems. Silva et al.

(2004) proposed a model to irrigation system evaluation with factor of adequacy to the calculus of gross water depth to be applied that lodges in only one indicator the measures of uniformity and efficiency of application.

But, most research works show that model efficiency parameters and uniformity coefficients of water depth applied are obtained during only one test in conditions of low or no wind and without crop presence and normally, it does not consider effect of plants development and also mulching on surface, in water redistribution on soil profile provided by water depth applied and in crop productivity. Beside it, environmental factors such as speed and direction of wind, temperature, moisture content can change constantly on irrigated period, modifying uniformity values of distribution for each irrigation event (Li & Rao, 2000).

MATERIAL AND METHODS The experiment has been carried on typical oxisol, with medium density around 1.200-1.300 kg m^{-3} and field capacity around 0,32 m^{-3} m^{-3}, placed on experimental area of Agricultural Engineering College of Unicamp (Feagri/Unicamp) in Campinas, Sao Paulo State, Brazil, and geographical coordinate are: Latitude 22°48´57” south, longitude 47°03´33” west and altitude around 640 m. Chemical and particle size analysis indicated results: pH ($CaCl_2$): 5.8; Ca^{2+}: 65.0 mol_c m^{-3}; Mg^{2+}: 11.0 mol_c m^{-3}; P: 33.0 mol_c m^{-3}; K: 7.4 mol_c m^{-3}; areia: 310 g kg^{-1}; silte: 158 g kg^{-1} e argila: 532 g kg^{-1}.
Planting fertilization was carried based in information obtained through soil analysis, using 200 kg ha^{-1} by formulation 04-14-08. 120 kg ha^{-1} of ammonium sulfate has been applied on side dressing fertilization, shared to the 30 and 60 days after plants emergence, according recommendation of Ambrosano et al. (1996). Four areas has been delimited to carry these tests with 25 m^2 (5 m x 5 m) of useful area for each, every conducted by no-tillage system with 4, 6, 8 and 12 t ha^{-1} of mulching of millet, cultivated with bean crop, variety Pérola, planted at 06/11/2008, spaced of 0,5 meters between lines and planting density around 10 to 12 plants for linear meter.

Weed control to implantation of tests was carried at 06/09/2008, applying “Roundup” dosed in 5 L ha^{-1}, and posterior application of “Robust” at 07/04/2008 dosed in 1 L ha^{-1}, and post bean crop emergence. Sprinkler Irrigation system was composed by two lateral lines with 3 sprinklers for each one, NaanDan Jaim 427 AG model, flow rate of 0,45 m^3 h^{-1} under pressure of 196.0 kPa, wet diameter of 22 m and spacing 12 m x 12 m.
25 Collectors has been installed for each experimental area, belong in a regular mesh of 1 m x 1 m to calculate the medium water depth collected (A) after every irrigation cycle and relation of irrigation efficiency parameters obtained through mathematic models of linear and normal distribution for each stage of crop with grain productivity. Soil moisture content (B) was determined under 0.20 m depth through gravimetric method and 24 hours after ending of each irrigation cycle. Soil samples to determine moisture content has been obtained in places next each collector.

Application uniformity was determined through Christiansen Uniformity Coefficient (CUC) for each irrigation on surface (C) and soil profile (D) obtaining medium values of these parameters for each crop development stage (equation 1).

$$CUC = 100\left[1 - \frac{\sum Z_i - \bar{Z}}{\bar{Z}\, N}\right] \quad (1)$$

Where:

CUC - Christiansen Uniformity Coefficient, (%);
Z_i - Water depth collected on collector 1, (mm);
$\bar{Z}$ - Medium water depth, (mm);
N – Total numbers of Collectors.

The Christiansen Uniformity Coefficient for each stage of crop has been calculated through accumulation of water depth collected in each collector of same position on mesh, originated of irrigations belong to different plant growing stages analyzed. Irrigation management has been carried on irrigation schedule, based on evapotranspirated water depth reposition estimated through crop coefficient along bean crop cycle and reference evapotranspiration, that take in vegetative development stages (DV); flowering (FL); grains filling (EG) and physiological maturation (MF).

Penman-Monteith equation modified by FAO (Allen et al., 1998) has been applied to estimate the reference evapotranspiration, with climatic dates obtained on Campbell meteorological station, with data logger model CR 10 X, installed next to the test place.
In the same periods, linear and normal mathematic models has been applied, proposed by Karmeli et al., (1978) and by Walker (1979) respectively, for each treatment to irrigation efficiency parameters determination: Application Efficiency (EA), Storage Efficiency (ES), depth percolation (PP) and deficit area (Ad). Mathematic models application to irrigation evaluation needs a previous knowledge of water depth required (Yr) defined by equation 2.

$$Yr = \frac{DUS}{\bar{Y}} \quad (2)$$

Where:

Yr – water depth required;
DUS – moisture content deficit on root zone, (mm);
$\bar{Y}$ - Medium water depth collected, (mm);

Grains production has been estimated through collect of three plants more next each collector, with data analysis carried through Student tests in a level of 95% of confidence.

RESULTS AND DISCUSSIONS Total water depths collected on 4, 6, 8 and 12 t ha^{-1} treatments were 172.41 mm; 117.31 mm; 122.02 mm; and 174.59 mm, respectively. Total rain precipitation occurred during tests was 79 mm, obtained mainly on crop flowering stage. Water depth values collected, as well as, moisture content on soil profile and CUC on and under soil surface, for each crop development stage are showed at Table 1.

Table 1. Medium values of water depths collected (A- mm), moisture content on soil profile (B - %) and Christiansen Uniformity Coefficient (CUC) on surface (C - %) and soil profile (D - %) for each developments stage to bean crop on no-tillage system with different quantities of mulching.

Crop stage and (medium water depth applied)	Evaluated parameters	Treatments ($t\ ha^{-1}$) 4	6	8	12
DV - (4.5 mm)	A	6.32	5.30	5.50	6.60
	B	31.71	32.53	33.62	33.74
	C	82.65	83.41	78.38	80.76
	D	94.08	93.95	93.24	92.97
FL - (6.0 mm)	A	11.70	7.43	8.02	12.12
	B	33.77	33.00	34.09	34.00
	C	82.54	84.14	89.14	77.35
	D	94.19	95.35	93.24	92.87
EG – (6.0 mm)	A	15.37	10.03	10.48	15.43
	B	32.83	30.94	30.86	31.79
	C	88.20	83.94	84.73	82.79
	D	93.04	88.51	88.27	91.78
MF – (7.5 mm)	A	13.45	8.95	7.67	12.85
	B	30.50	28.33	28.40	34.10
	C	80.92	83.15	84.73	82.79
	D	93.43	90.10	88.80	86.93

In a general way, every treatments indicated medium values of CUC on soil profile higher to the values obtained on surface, with values next or superior of 90%, demonstrating a kind of redistribution of applied water depth on soil surface, independent of mulching quantity present on its surface. Treatment 12 t ha^{-1} of mulching indicated lower value of CUC soil interior on MF stage (86.93 %). CUC values on soil surface were higher than 75%, which is considered satisfactory to field conditions. Speed and wind directions has been monitored during irrigation cycles, and it has been southwest direction predominant and medium speed around 1.7-3.5 m s^{-1}. CUC values of this test has been next to the values obtained by Li & Rao (2000) which studying the canopy effect of wheat winter crop cultivated in Beijing on the application uniformity concluded that wheat canopy tends to improve the uniformity of sprinkler irrigation application.

Similar results has been obtained by Roque (2007), that analyzing the uniformity effect of water distribution on soil surface and its redistribution on soil profile on the bean crop irrigated by sprinkler irrigation system verified an increasing of uniformity coefficient along the time, with values obtained around 90 %. Moisture content under soil surface is an important aspect to be considered about irrigation management, because system acquisition provides higher levels of uniformity on surface can cause a significant increasing of costs implementation and consequently increasing in operation costs of irrigated systems.

It is observed on table 1, that the water depths collected on 4 and 12 t ha^{-1} treatments were higher to the other treatments during every stages of crop development. It occurred, probably, in function of arrangement of sprinklers in field and also through wind speed and direction predominant in experimental area, which in some irrigations had obtained values of 3.5 $m.s^{-1}$. About DV stage, medium water depth collected indicated values higher 5 mm for every treatments, and the highest values has been obtained at 4 t ha^{-1} (6.32 mm) and 12 t ha^{-1} (6.6 mm), becoming values of moisture content on soil profile indicated values higher than field capacity (31%).

About FL stage, medium water depths collected has been higher than values obtained in DV, due to the fact of plants is needed of a bigger quantity of water to its development, being necessary a higher water depth to be applied. Similar situation occurred during EG stage, but 6 and 8 t ha^{-1} treatments indicated values of moisture content on interior soil lower of field capacity. It can be occurred due the lower values of uniformity on soil profile, 88.51% and 88.27%, respectively, when it is compared to the other treatments, in the same way that water depths collected had been higher in 22% and 26% to the medium water depth applied in the same period to these same treatments.

It cannot be realized on FL, because although water depths collected in these treatments had been next to water depth applied, it is observed that water redistribution on soil had lower variation in this stage, with CUC values around 95.35 % and 93.24% to the 6 and 8 t ha^{-1} treatments, respectively, possibiliting medium values of moisture content on profile, higher up field capacity for both treatments. About MF, there was only one irrigation cycle and after that it was stopped due the senescence could be started.

In this stage, water depths collected indicated values more next water depths applied (7.5 mm), obtaining on 6 and 8 t ha^{-1} treatments, resulting medium values of moisture content on soil profile next to critical considered values to the bean crop (28%), but it occurred in the end of cycle crop, without enormous damages to the grains productivity. Bean crop is not so much tolerated to the water deficit, possibiliting significant decrease of productivity, in the event occurring on flowering and filling grains, due its low capacity to get over after stress and its root zone not much developed (Mouhouche et al., 1998).

About obtained dates of water depth collected by collector, after each irrigation event, it has been possible to apply mathematic models for each stage of bean crop and for every treatment analyzed. Table 2 shows values of irrigation evaluation parameter obtained through linear and normal models and crop productivity. It is observed that 6 and 8 t ha^{-1} treatments obtained the highest values of Application Efficiency (EA) in every crop development stages on two analyzed models, with values or higher than 80%, on stages DV, FL and EG. Probably due the fact of these treatments have been received water depths with values more next to the applied water depths, in every plants development stages.

It is observed that these same treatments had the highest uniformity values of application on surface, independently of applied model (Table 1), in other words, in this research work, the EA had direct relation with uniformity of application on surface. Same situation is not occurring on research work carried by Ascough & Kiker (2002) which conducted it on South Africa, in relation to the uniformity evaluation of application in different irrigation systems and concluded that in some cases, irrigation systems demonstrated a higher EA, even with bad distribution uniformity. In other words, although water can be used efficiently, areas with crop that cannot be receiving adequate water quantity.

Table 2. Irrigation quality parameters: Application Efficiency (EA); Storage Efficiency (ES); Depth Percolation (PP) and Water depth required (Yr), obtained through mathematic models for each irrigated bean crop stage and estimated productivity (P).

				Linear model			Normal model		
Treatment	P	Stage	Yr	EA	ES	PP	EA	ES	PP
(t ha^{-1})	(Kg ha^{-1})				(%)				
4	1812.0[a]	DV	0.71	71.0	100.0	20.0	71.0	100.0	29.1
		FL	0.49	49.0	100.0	51.0	49.0	100.0	50.9
		EG	0.40	40.0	100.0	60.0	40.0	100.0	60.3
		MF	0.56	56.0	100.0	44.0	56.0	100.0	44.2
6	1731.0[a]	DV	0.85	85.0	100.0	15.0	84.0	99.0	16.0
		FL	0.78	77.0	99.0	18.0	77.0	98.0	23.1
		EG	0.60	60.0	100.0	40.0	60.0	100.0	39.6
		MF	0.90	84.0	93.0	16.0	85.0	95.0	15.1
8	1625.0[a]	DV	0.81	80.0	99.0	14.0	79.0	97.0	21.4
		FL	0.78	77.0	100.0	15.0	77.5	100.0	22.6
		EG	0.56	56.0	100.0	31.0	56.0	96.0	43.6
		MF	0.98	96.0	100.0	6.0	93.0	100.0	6.6
12	2494.0[b]	DV	0.69	69.0	100.0	19.0	68.0	99.0	32.0
		FL	0.49	49.0	100.0	51.0	48.0	99.0	51.8
		EG	0.39	39.0	100.0	61.0	39.0	100.0	60.6
		MF	0.59	58.0	100.0	42.0	56.0	96.0	43.8

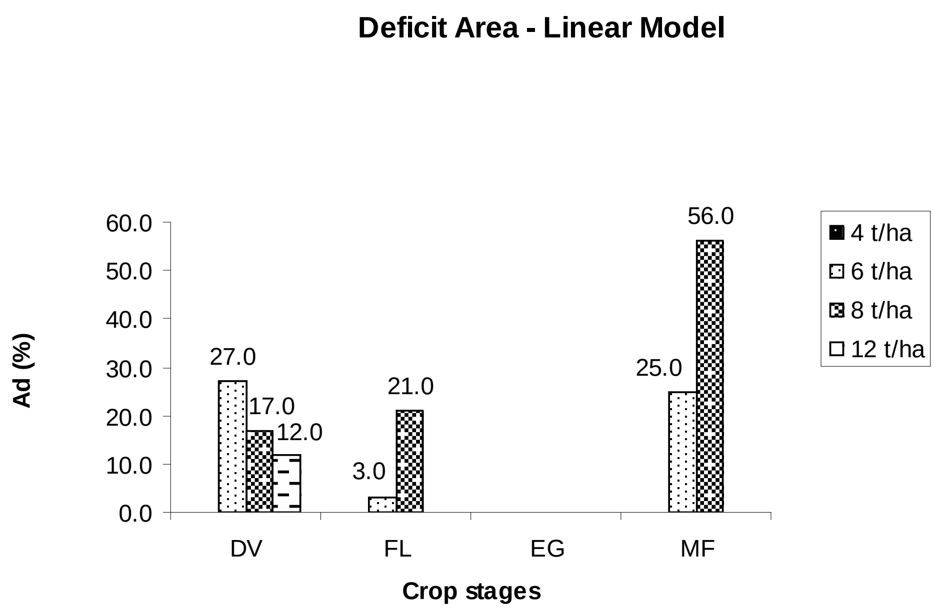
[a,b] Medium values followed for same letter has not been statistically different through Student test to 5%..

The values obtained of EA through two models showed very next for each stage and evaluated treatment. Similar situation is occurring in relation to the ES whose values reached values next to 100%, indicating that irrigated water depth was storage on root zone, and it can occurs as in deficit irrigations or water excessive applying.
But, treatments that received higher quantities of water (4 and 12 t ha^{-1}) showed the highest values of PP as on linear model as on normal model on FL and EG stages with values varying between 51 and 61%. The linear model showed similar values in relation to the normal model to this same parameter when water depth required calculated (Yr) was lower than medium water depth value (Y = 1) and also to the minimum water depth applied, resulting loss for PP in 100% of area. It also occurred, when water depth required was lower than the maximum water depth and higher to the value of minimum water depth applied, but with value next to “1”, which was observed in this case, a bigger area with loss for PP. Both cases and models, PP has been obtained through difference of 1-EA.

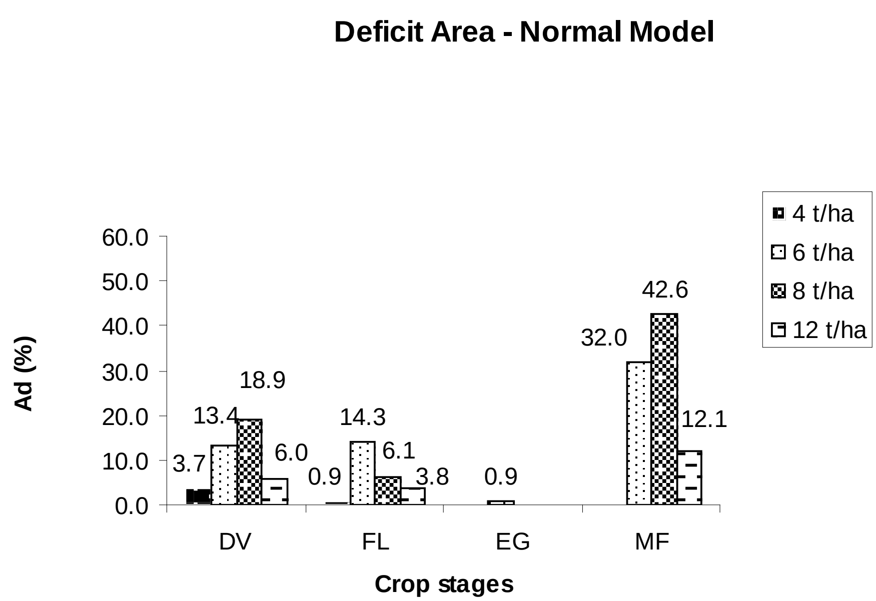
About other situations, the normal model showed values higher to the values obtained through linear model in relation to the same parameter, when water depths required was lower than the value of maximum water depth and higher than the value of minimum water depth applied, resulting in part of are with losses for PP and part of area with moisture content deficit. Then, calculus of PP through linear model and minimum water depth has been considered and how this commonly this number has been lower than “1”, obtained results through this model has been every lower than the values obtained through normal model to this situation. It can be observed on DV stage to the 4, 8 and 12 t ha^{-1} treatments, whose values obtained on normal model, had been higher in 31%, 33% and 41%, respectively. Same situation occurred to the FL stage to treatments with 6 t ha^{-1} (22%) and 8 t ha^{-1} (34%) and on EG stage to the treatment with 8 t ha^{-1}, whose values obtained through normal model has been 43.6%, being 29% higher than the value obtained through linear model.

Figure 1 shows deficit area values (Ad %) obtained using both analyzed models for each evaluated treatment and crop stage. It is noted that, through these models, water depths collected has been higher than the water depths applied on EG stage and, practically, there was not deficit area on treatments, indicating 100% of area irrigated with excessive water. The 6 and 8 t ha^{-1} treatments showed the highest deficit areas for both models analyzed in the crop cycle. Through linear model, it is observed that treatments 6 and 8 t ha^{-1} had 27.0 and 17.0 % (DV); 25.0 and 56.0 (MF), respectively, of irrigated area with water deficit. About normal model, these same parameters showed values of 13,4 and 18.9 % (DV); 14.3 and 6.1 (FL); 32.0 and 42.6 % (MF). Treatment with 12 t ha^{-1} through linear model indicated that only 12% of irrigated area with water deficit only in the DV. About normal model, these values has been around 3.81% (FL) and 12.1% (MF), Treatments with 4 t ha^{-1} has not indicated any deficit area.

It shows that, same treatments that indicate higher values of EA and lower values of PP (6 and 8 t ha^{-1}) estimated through two analyzed models, with water depths collected more next to water depths applied, indicated the highest areas irrigated with water in deficit. It has influenced on plants productivity, whose values obtained was 1.731,0 and 1.625,0 kg ha^{-1}, respectively.



a)



b)

Figure 1. Deficit areas estimated through linear (a) and normal (b) models for each treatment with different quantities of mulching and development stages to irrigated bean crop by sprinkler irrigation system.

Inverse situation has been observed on treatments irrigated excessively (4 and 12 t ha^{-1}), with low EA due the high values of PP estimated through mathematic models applied, where there was better water disposition to plants, mainly on FL and EG stages, improving the crop productivity.

The plants of treatment with 4 t ha^{-1} obtained productivity higher in 5 and 10% in relation to the plants of treatment 6 and 8 t ha^{-1}, respectively. Higher productivity has been obtained through plants of treatments with 12 t ha^{-1} (2.494,0 kg ha^{-1}, with values higher in 27, 31 and 35% that plants submitted to the treatments with 4, 6 and 8 t ha^{-1}. Higher quantity of mulching on treatment 12 t ha^{-1} improved moisture content conservation on root zone, increasing water disposition to the plants.

In search of raise productivities with inadequate use of water resources is common in many agricultural regions. Then, there is necessity that irrigated agriculture be more efficient, which is related to uniformity of systems application, as on surface as on soil profile, so water can be used on irrigated agriculture in a more rational way, and in the same time, with satisfactory levels of productivity.

CONCLUSION Higher quantities of mulching has not influenced on water applied retention, occurring some redistribution of this water on root zone, 24 hours after the end of irrigation cycle, on different stages of crop development.

The mathematic models analyzed indicated same behavior on evaluated parameters obtaining for each crop stage to different treatments, in exception about some evaluations of depth percolation parameter, which normal model showed same values in relation to the linear model.

The evaluation parameters of quality irrigation obtained through mathematic models evaluated reproduced the same field conditions to this test in relation to the water depth collected, as in deficit as in excessive water, with crop productivity and not only in a simple field system hydraulic evaluation, used to verify if purposed system answer irrigation project technical specifications.

Treatments with 4 and 12 t ha^{-1} showed lower values of application efficiency, collected water depths in excessive and higher values of productivity, being the treatment 12 t ha^{-1} differed statistically through Student test in 95% of confidence in relation to other treatments.

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