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MODELO PARA ESTIMATIVA DO RENDIMENTO DE CULTURAS IRRIGADAS BASEADO NO BALANÇO HÍDRICO SEQUENCIAL: APRESENTAÇÃO E APLICAÇÃO

MARCO ANTÔNIO JACOMAZZI[1]; JOSÉ ANTONIO FRIZZONE[2]; ASDRUBAL JESUS FARIAS RAMIREZ[3]; MARIA ALEJANDRA MORENO-PIZANI[4]; FABIO TOMASELLA JOHANSSON[5] E SERGIO NASCIMENTO DUARTE[6]

[1]-Mestrado Profissional em Rede Nacional em Gestão e Regulação de Recursos Hídricos - ProfÁgua, Universidade Federal do Rio Grande do Sul – UFRGS, Av. Bento Gonçalves, 9500, 91501-970, Porto Alegre/RS, (19) 98156-4809, marcoantono@rasa.eng.br
[2] Departamento de Engenharia de Biossistemas, Escola Superior de Agricultura "Luiz de Queiroz", Av. Pádua Dias nº11, Bairro São Dimas, Piracicaba – SP, Brasil, CEP: 13.418-900, frizzone@usp.br
[3] RASA Engenharia, Edifício Racz Center, R. Alfredo Guedes nº 1949, sala 506, Higienópolis, Piracicaba- SP, cep: 13.419-080, Brasil, ajfara@gmail.com.
[4] PECEGE, R. Alexandre Herculano, nº 120, T6, Vila Monteiro, Piracicaba – SP, cep: 13.418-455, Brasil, morenom76@gmail.com.
[5]-Departamento de Engenharia de Biossistemas, Escola Superior de Agricultura "Luiz de Queiroz", Av. Pádua Dias nº11, Bairro São Dimas, Piracicaba – SP, Brasil, CEP: 13.418-900, fabiojohansson@usp.br.
[6] Departamento de Engenharia de Biossistemas, Escola Superior de Agricultura "Luiz de Queiroz", Av. Pádua Dias nº11, Bairro São Dimas, Piracicaba – SP, Brasil, CEP: 13.418-900, snduarte@usp.br.

1 RESUMO

Agricultura moderna tem utilizado recursos computacionais para planejar o uso racional da água em sistemas irrigados. O constante avanço tecnológico destes recursos torna necessária a atualização dos softwares desenvolvidos para a área de irrigação, incorporando tecnologias mais recentes. O objetivo deste trabalho foi elaborar uma ferramenta computacional de fácil acesso, que permitisse ao usuário escolher critérios para as áreas irrigadas, e apresentar um exemplo de aplicação. Esse programa foi desenvolvido para auxiliar na tomada de decisão sobre o nível de manejo de irrigação suplementar a ser adotado, levando em consideração as chuvas a partir de uma série histórica de dados e a máxima produtividade esperada para a cultura. O aplicativo requer dados de parâmetros climáticos regionais, características da cultura irrigada, propriedades do solo e manejo de água adotado como entrada. Ele permite estimar a evapotranspiração de referência usando quatro métodos diferentes a partir dos dados climáticos disponíveis. Simulações realizadas para a região de Piracicaba - SP, onde o déficit hídrico não é acentuado, mostraram as diferenças no nível de depleção da água do solo adotado foram insignificantes. Entretanto, essas diferenças podem ser potencializadas para regiões mais áridas. Essa ferramenta pode ser útil para usuários de diferentes regiões climáticas no país.

Keywords: Modelagem, Manejo da Irrigação, Irrigação Suplementar.

JACOMAZZI, M.A.; FRIZZONE, J.A.; RAMIREZ, A.J.F.; PIZZANI, M.A.M.; JOHANSSON, F.T.; DUARTE, S.N.

MODEL TO ESTIMATE IRRIGATED CROP YIELD USING SEQUENTIAL WATER BALANCE: PRESENTATION AND APPLICATION

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2 ABSTRACT

Modern agriculture has been using computer resources to plan the rational use of water in irrigated systems. Due to the constant advancement of these resources, it is necessary to update the software developed for the irrigation sector, incorporating newer technologies. The objective of this work was to develop a user-friendly computational tool that would allow the user to choose criteria for irrigated areas and provide an example of application. This program was developed to assist in the decision-making process regarding the level of supplementary irrigation management to be adopted, taking into consideration rainfall from a historical series of data and the maximum expected productivity for the crop. The application requires regional climatic parameter data, characteristics of the irrigated crop, soil properties, and water management adopted as input. It allows the estimation of reference evapotranspiration using four different methods based on available climatic data. Simulations conducted for the Piracicaba region in Brazil, where water deficit is not significant, showed that differences in the adopted soil water depletion level were insignificant. However, these differences may be amplified for more arid regions. This tool can be useful for users from different climatic regions in the country.

Keywords: Modeling, Irrigation Management, Supplementary Irrigation.

3 INTRODUCTION

Irrigation management refers to the careful use of available water resources to achieve a specific objective, such as high crop productivity through the efficient use of water, energy, and other production resources. Conventional irrigation practices are based on two key specifications: crop water requirements and water use efficiency (SILVA et al., 2020).

To support the formulation of irrigation calendars, for many years, research guided by various ideas about the desirable level of soil water use has attempted to relate crop production to the amount of water (CAPORUSSO; ROLIM, 2015).

Thus, two basic principles have been established for irrigation management: (i) irrigation for maximum production per unit area—for this purpose, the crop's water needs are fully met to avoid losses in productivity or product quality (DOORENBOS; PRUITT, 1977)—and (ii) irrigation to maximize production per unit volume of water applied—for this purpose, the aim is to save water by increasing the efficiency of water application, assuming that water availability constitutes a limitation to agricultural production (MARTIN et al., 2012; SILVA et al., 2020).

The recommended efficiency levels are those achievable with an irrigation adequacy level of approximately 90% for high- or medium-value crops or approximately 75% for low-value crops. Conventional irrigation is thus defined in terms of the amount of applied water required to avoid water deficit 75% or 90% of the time (return periods of 4 or 10 years) (GURSKI et al., 2021).

The degree of irrigation adequacy affects the proportion of the area that must receive sufficient water to avoid productivity losses. When the irrigation depth is lower than the crop's water needs, the degree of adequacy decreases, and productivity decreases. However, this scenario also results in less percolation, greater water application efficiency, lower irrigation operating costs, and reduced chemical leaching.

The ability of irrigation to fully meet crop water demands is a relatively simple and clearly defined problem with a single objective. However, a fundamental shift in irrigation practices is expected in the coming years due to economic pressures on farmers, increasing competition for water use, and the environmental impacts of irrigation. These factors are expected to motivate a paradigm shift in irrigation, focusing more on economic efficiency (PERRY et al., 2009) than on maximum crop water demand.

Climate change, the technological development of industrial activities, and population growth, all of which place increasing demands on water resources, have intensified competition for irrigation water. Therefore, the implementation of integrated water resource management actions to meet its multiple needs is urgently needed (GURSKI et al., 2021).

Traditional irrigation management is based on maximizing production per unit area without explicitly considering costs and profits. On the other hand, irrigation optimization takes these economic factors into account to maximize profitability, which is a more complex challenge. Identifying optimal irrigation strategies requires the use of detailed models that consider the relationships between water and crops, as well as irrigation efficiency. Furthermore, it is necessary to explicitly incorporate economic factors such as production costs, product prices, and the opportunity costs of water into the analyses.

The Brazilian irrigation sector still follows traditional short-term approaches commonly used to design irrigation systems, without considering the contribution of precipitation to partially meeting the water needs of crops and the regional water availability of rivers and streams (PAULINO et al., 2011).

To implement strategic programs for local or regional agricultural development that consider the availability of surface water resources, it is essential to quantify the water needs of crops throughout the production cycle in a probabilistic manner.

An effective technique for estimating crop water consumption for irrigation purposes is the water balance. This technique is widely used because it allows for the estimation of temporal variation in soil water storage, with estimates of actual evapotranspiration (PHOGAT et al., 2017), water deficit, water surplus, and supplemental irrigation depth.

The use of probabilistic models (YU et al., 2016) to quantify the frequency of climatological events, such as effective precipitation depth, extreme events, or potential evapotranspiration, has been widely studied in recent years. Some of the main advantages of applying probabilistic distributions to climate parameters include quantifying the need for supplemental irrigation of commercial crops, providing support for appropriately sizing irrigation system capacity, and estimating the risk of crop failure and economic failure of irrigated agricultural activities (PRADO et al., 2020).

The purpose of this paper is to present the development and application of a computational model that uses sequential water balance simulations to quantify crop yield and yield declines probabilistically, considering irrigation water application. The model uses a historical series of years to perform simulations and obtain accurate estimates of crop irrigation needs. These estimates are crucial in water-restricted scenarios, enabling informed irrigation management decisions.

4 MATERIALS AND METHODS

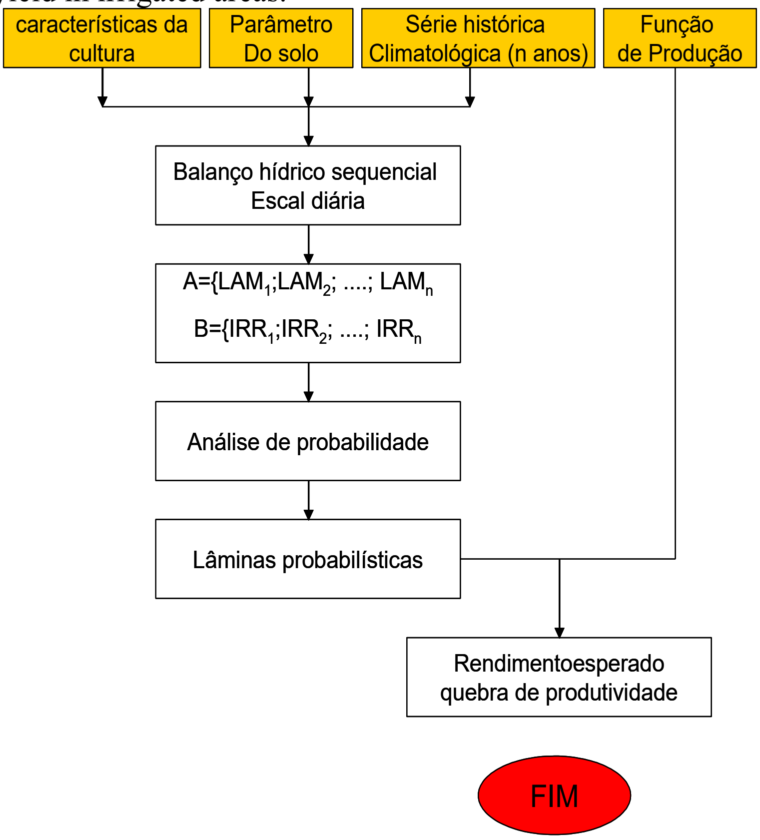
4.1 Description of the computational model

The developed computational model allows us to estimate the expected crop yield in irrigated areas, as well as calculate the accumulated water depths throughout the crop cycle. This model is based on the simulation of supplemental irrigation through sequential water balances on a daily basis, using a historical series of user-provided data.

Crop available water depth (LAW) values are calculated, taking into account simulated rainfall and supplemental irrigation, or just the net supplemental irrigation depth (IRR), both of which accumulate over the crop cycle. A probability analysis is then applied to these values.

Using the probabilistic LAM values in specific production functions, it is possible to estimate the expected average yield for the crop. Figure 1 presents the results of these estimates.

Figure 1. General flowchart of the computational model developed in this work to estimate crop yield in irrigated areas.



Source: Jacomazzi (2004)

The computational model was coded in the Visual Basic language via Excel platform spreadsheets.

The model requires the following input parameters:

- Soil properties:
- Parameters of the van Genuchten equation: α; θs; θr; n; m;

Crop characteristics:

- Effective depth of the root system;
- Cycle duration (in days or accumulated degree days);
- The cycle duration for the root system to reach the maximum depth;
- Critical matrix potential of culture;
- Time to suspend irrigation;
- Crop response to irrigation or production function in relation to water.

Climate data:

- Daily precipitation data; and

- Selection of the reference evapotranspiration estimation model and corresponding necessary climate data.

4.2 Defining the irrigation period

The ideal time for water application to the soil, known as the irrigation time, is defined by determining the minimum soil moisture content (θMIN), which corresponds to the critical soil water tension (ΨCRIT). This critical tension is established at the point at which a significant reduction in crop yield occurs.

θMIN is obtained by using a constant ΨCRIT value throughout the crop cycle over a given time horizon and considering the soil water retention curve via the van Genuchten model. The parameters of this model are entered at the beginning of the operational routine and used to calculate the minimum soil water storage (ARMMIN). On the basis of these data, it is possible to determine the most appropriate time for soil water application to ensure the maximum yield of the irrigated crop.

4.3 Estimating the length of the crop cycle

There are two proposed approaches for estimating crop cycle length: the first is the accumulated degree-day (GDA) estimate, and the second is the accounting of successive days after emergence (DAI). The accumulated degree-day method assumes that crop development is influenced by weather during its cycle. When the production factors are in balance and there are no constraints, the plant performance is maximized. In this method, the length of successive crop cycles is determined on the basis of the sum of thermal units or degree days.

In the method of counting the successive days of the cycle after emergence, the cycle length is determined from direct observations of crop development, counting the successive days from emergence to maturity. This approach does not consider climate variations that can influence crop development. Both approaches have advantages and disadvantages, and the most appropriate approach should be chosen for each specific situation.

4.4 Variation in potential soil water storage capacity

According to Pereira, Villa Nova and Sediyama (1997), the general equation for calculating the available soil water capacity (AWC) for a given depth can be determined via equation (1).

$$CAD = \left(\theta cc - \theta pmp\right)\sum z_{EF} \quad (1)$$

where:

θ_{CC} – Moisture based on volume, at field capacity, m3m-3;

θ_{PMP} – moisture content on the basis of volume at the permanent wilting point, m3m-3; and

z_{EF} - effective depth of explored soil, mm.

Permanent wilting point moisture is defined as the soil moisture corresponding to a water tension of 1,500 kPa, although the concept itself is difficult to define. The soil characteristic curve is used to obtain these moisture values, according to the regression model of Van Genuchten (1980).

According to Dourado Neto and Van Lier (1993), the depth of the root system (zROOT) progresses linearly from an initial value until it reaches a maximum depth, or root growth may follow a sigmoidal pattern.

To consider both methodologies described above, a simplification for estimating the zRAIZ is proposed on the basis of the following criteria:

- zRAIZ values with their respective crop development indices (IDCs) in the form of a table;
- From these values, straight line segments are drawn that interconnect the zROOT (IDC) sequentially;
- The zRAIZ (IDC) value is the result of linear interpolation between the two closest tabulated values.

Although root growth is continuous, it is not possible to measure the soil water status continuously throughout the explored profile, as there is no commercially available equipment for this purpose. Therefore, it is common to divide the soil profile into layers and install monitoring equipment at reference depths (zREF), which represent the average of the corresponding layers.

- To ensure that the soil water replenishment simulations are consistent with usual irrigation management practices, the following criteria are adopted: irrigation management is similar to instruments measuring the soil water status, such as capacitance probes, tensiometers or TDRs;
- The depth used to calculate CAD follows the development of root depth (zROOT) in a stratified manner. Thus, the total depth is divided into layers, each with a reference depth (zREF). The layer depth is considered only in the calculation of the effective soil depth when root growth reaches zREF, that is, when zROOT > zREF.

4.5 Determination of reference evapotranspiration (ETo)

to estimate reference evapotranspiration (ETo). Table 1 summarizes the main climate variables required for each model that can be used by the program as options.

Table 1. Climatic variables required for each reference evapotranspiration (ETo) estimation model.

Models	Temperature	Humidity Relative	Wind	Radiation	Evapotranspiration
Penman–Monteith	X	X	X	X	
Priestley -Taylor	X			X	
Thornthwaite	X				
Class A Tank		X	X		X

Source: Jacomazzi (2004)

In addition to these ETo estimation models (ČADRO et al., 2017), the program also allows the user to directly insert the ETo value into the sequential water balance if the calculated data are already available.

4.6 Determination of crop evapotranspiration (ETc)

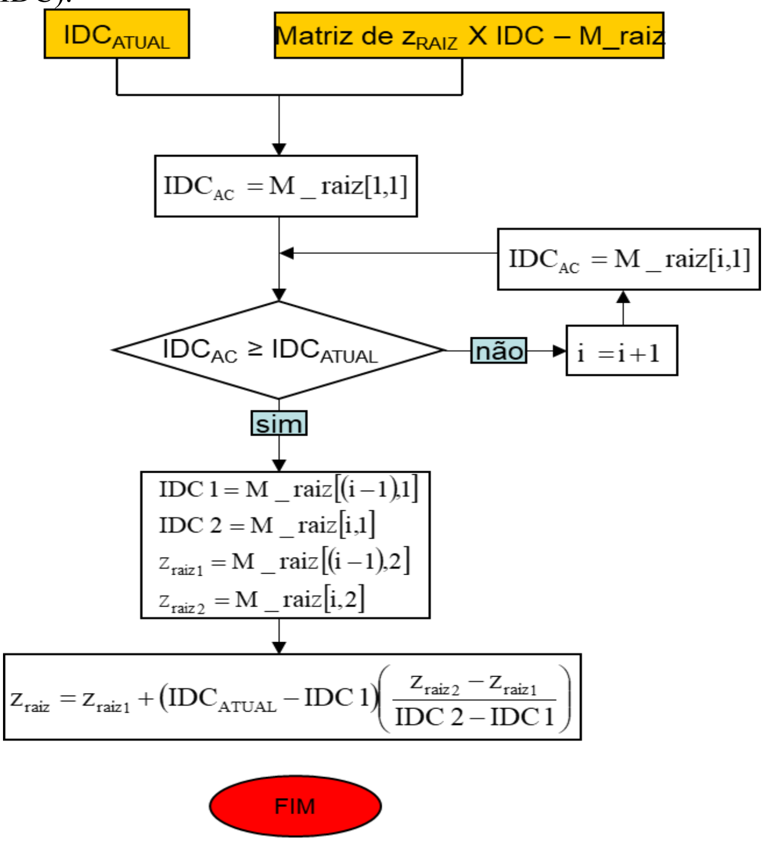
Equation (2), which was proposed by Doorenbos and Kassan (1979), is used to estimate water consumption by a crop without water limitation. In this equation, the crop coefficient Kc (IDC) relates the maximum crop evapotranspiration (ETc) with the reference evapotranspiration (ETo).

$$ETc = kc\left(IDC\right)ETo \qquad (2)$$

The crop coefficient (Kc) is influenced by the crop development stage and is measured in days or degree days. Therefore, this coefficient varies according to the current phenological stage of the crop, which includes physiological events and leaf area evolution. The tabulated Kc values proposed by FAO-24 in 1994 and revised by Allen (1998) describe the evolution of Kc through four linearized segments.

To simplify the estimation of Kc, an approach similar to that used in the estimation of root system growth is proposed, considering both days after emergence and degree days.

Figure 2. Flowchart for determining the crop coefficient (Kc) as a function of the cycle duration index (IDC).



Source: Jacomazzi (2004)

4.7 Sequential daily water balance

One approach to estimating the water balance in a soil system is based on the analysis of water inputs and outputs in a specific soil volume, where water storage is quantified in real time (LOPES et al., 2017; MINACAPILLI et al., 2016). The main inputs considered in this system are precipitation (CH) and net irrigation depth (IRR), and excess water that exceeds the soil's storage capacity is considered water loss, either through deep percolation or surface runoff.

Different methodologies, such as those proposed by Braga (1982) and Dourado Neto and Van Lier (1993), combine existing criteria and theories, such as those used by Doorenbos and Pruitt (1977), Pereira, Villa Nova and Sentelhas (1997) and Camargo et al. (1999), to consider the actual crop evapotranspiration (ETR) considering the crop, the atmospheric demand measured by the reference evapotranspiration (ETo) and the availability of water in the soil, measured by the fraction of available water (FAD).

This sequential water balance model allows for the incorporation of planned irrigation management, defining a minimum storage capacity that determines the timing of irrigation and the gradual variation in the soil water storage capacity in a stratified manner. Importantly, this model can be used with both the soil water storage depletion model proposed by Braga (1982) and the model proposed by Dourado Neto and Van Lier (1993).

4.8 Estimation of the accumulated irrigation depth and the total accumulated water depth throughout the crop cycle

After each annual water balance is performed, the amount of water available for the crop cycle is calculated. This creates a historical record of water application with all simulated irrigation and rainfall events occurring during the same period, excluding excess water, which is considered a loss. Equations (3) and (4) show how the calculations are performed to record these water depths.

$$IRR_{AC} = \sum_{i=emergência}^{pmf} IRRi \quad (3)$$

$$LAM_{AC} = \sum_{i=emergência}^{pmf} (CH + IRR - EXC)_i \quad (4)$$

From this generated matrix, it is possible to obtain information regarding the operation of the irrigation system, which includes the total applied water depth due to irrigation only (IRRAC) and the total water depth (LAMAC) available to the crop (irrigation + rain – surplus), throughout the crop cycle.

4.9 Probability analysis

The model allows the adjustment of theoretical probability distributions on the basis of a matrix of water depth values, both total and irrigation only, to estimate the frequency of occurrence of an event with a certain probability.

The model includes two distributions: the normal distribution, which is most commonly used for continuous variables, and the two-parameter gamma distribution, which is defined for $x > 0$ and has parameters α and $\beta > 0$.

The Kolmogorov–Smirnov test is applied, which verifies the agreement between the known theoretical distribution (F) and the unknown distribution of the data (F°).

4.10 Estimating crop productivity and yield decline

The developed model considers that the crop response function to the available water depth is a polynomial equation, as shown in equation (5).

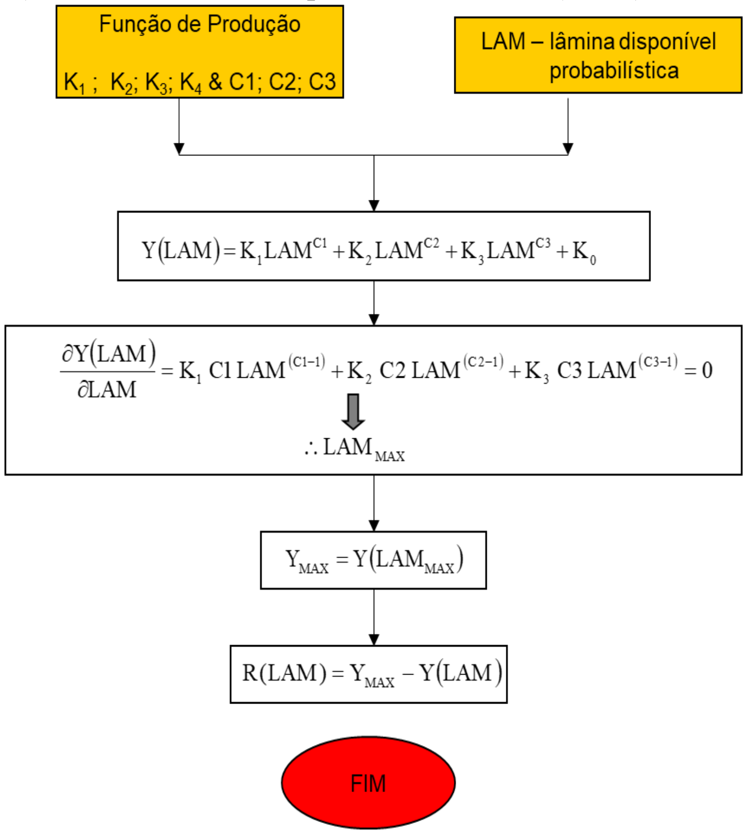
$$Y(LAM) = k_1\ LAM^{C1} + k_2\ LAM^{C2} + k_3\ LAM^{C3} + k_0 \quad (5)$$

where:
Y(LAM) - crop yield as a function of LAM $_{AC}$, kgha-1;
LAM - Total water depth available to the crop on a probabilistic basis, mm; and
k0, k1, k2, k3, C1, C2, C3 - adjustment coefficients of mathematical models.

The water depth-based yield estimation model has a probabilistic basis, which implies that the yield estimate also presents uncertainties (Figure 3). The maximum yield (YMAX) is obtained by taking the square root of the first derivative of the aforementioned equation. In turn, the yield drop [R(LAM)] is estimated by subtracting the maximum yield from the current yield, as shown in the following equation:

$$R(LAM) = Y_{MAX} - Y(LAM) \quad (6)$$

Figure 3. Flowchart for determining the average yield [Y(LAM)] and the drop in productivity [R(LAM)] as a function of the probabilistic blade (LAM).



Source: Jacomazzi (2004)

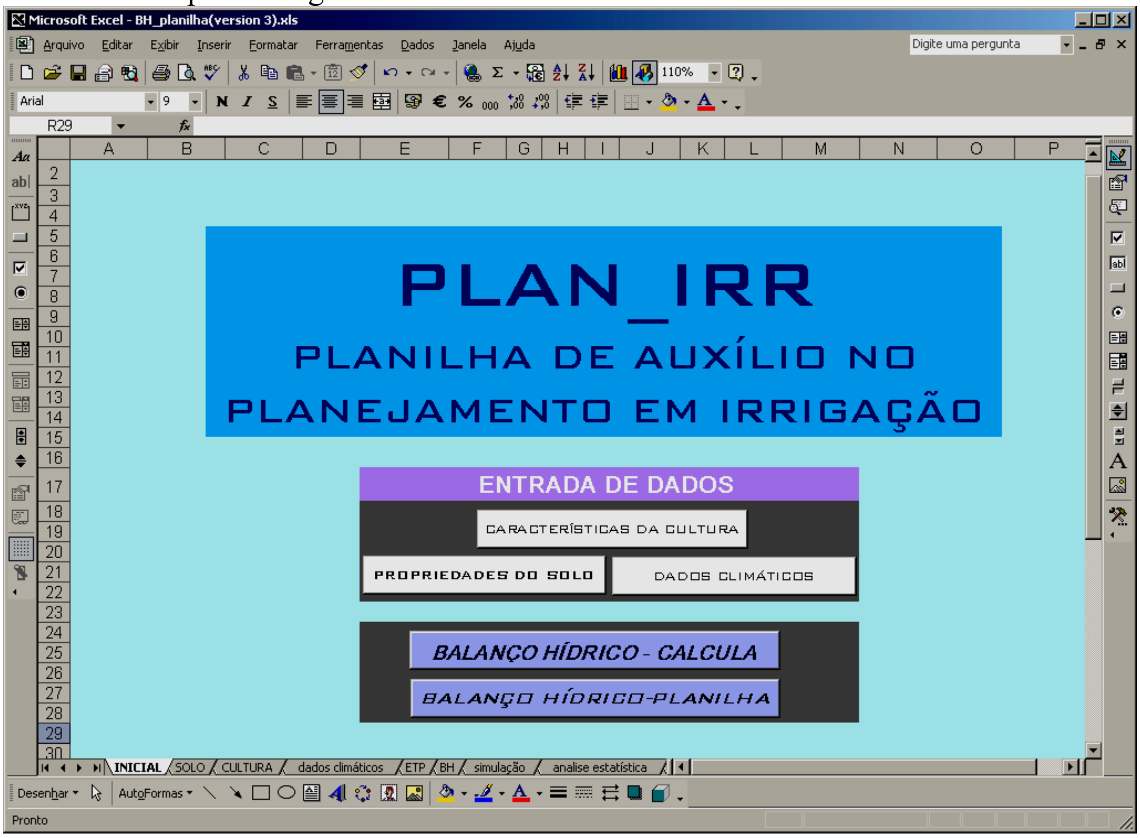
5 RESULTS AND DISCUSSION

5.1 Program Description

The program is a specific application to be used in the planning of irrigated systems. This program aims to assist in decision-making on (i) the level of irrigation management to be adopted; (ii) forecasting the occurrence of rainfall availability; and (iii) estimating the maximum expected crop productivity (BORGES JUNIOR et al., 2012; PANDEY; PANKAJ; DABRAL, 2016; YU et al., 2016) for a degree of irrigation service adopted (deficit irrigation).

The program interface (Figure 4) presents three options for data entry: crop characteristics, soil properties, and climate data. The program also provides two action options: calculating the water balance and viewing the results in the corresponding spreadsheet.

Figure 4. Home screen of the irrigation planning program with 3 data entry buttons and 2 to access processing actions.



Source: Jacomazzi (2004)

5.2 Application example

To illustrate the program's use and highlight its usefulness, the following example demonstrates its potential. The climate data used in this simulation were obtained from the meteorological station of the Department of Biosystems Engineering at the Luiz de Queiroz College of Agriculture, located in Piracicaba, São Paulo. This station is located at latitude 22°42'30" south and longitude 47°38'00" west, at an altitude of 546 meters. The proposed simulation used an irrigated "safrinha" corn crop.

5.2.1 Data used and criteria considered

5.2.1.1 Soil properties

Soil storage estimation model: van Genuchten. The equation parameters are presented in Table 2. Notably, these parameters are adjusted to the matric potential unit in kPa.

Table 2. Fitting parameters of the van Genuchten equation

N	M	α	θr	θs
1,3701	0.27012	0.5077	0.2172	0.46

Source: Jacomazzi (2004)

5 Matric potential at field capacity: 8 kPa;
6 Matric potential at the permanent wilting point: 1,500 kPa; and
7 Irrigation moments: tensions of 40, 75, 100 and 200 kPa.

Table 3 presents the volumetric moisture values calculated for the matric potentials at field capacity (ΨCC) at the permanent wilting point (ΨPMP) and at the irrigation times described above.

Table 3. The following irrigation management parameters were adopted: the volumetric moisture was estimated according to the matrix potential.

Ψm(kPa)	θ(m^3 m^{-3})
8	0.356
1500	0.238
40	0.296
75	0.28
100	0.274
200	0.261

Source: Jacomazzi (2004)

Table 4 presents the estimated values of unitary water storage, in mm mm-1, for the total available water capacity (f_CAD) and for the adopted irrigation times (f_IRR).

Table 4. Irrigation management parameters adopted and their respective estimated unit water storages

Name	Matric potential range in kPa	Unitary storage of water in mm mm^{-1}
fCAD	8-1500	0.12
F_ IRR(40 kPa)	8-40	0.060
F_IRR (75 kPa)	8-75	0.076
F_ IRR(100 kPa)	8-100	0.082
F_ IRR(200 kPa)	9-200	0.095

Source: Jacomazzi (2004)

The following model for estimating soil water depletion was adopted: Dourado Neto and Van Lier (1993); water extraction by the root system: growth up to 40 cm. The irrigation depth was 20 mm.

5.2.1.2 Culture characteristics

- Crop: “Safrinha” corn;
- Possible emergency date: March 10;
- Cycle length estimation model: Days after emergence (DAI);
- Crop cycle: 140 days; and
- Evolution of Kc in Table 5:

Table 5. Values of the Kc coefficient for corn crops (HEINEMANN; SOUSA; FRIZZONE, 2001) according to the respective days after the onset of emergence (DAI)

DAI	Kc
0	0.3
10	0.45
30	0.85
50	1,2
70	1.4
90	1.3
110	1.15
130	1

Source: Jacomazzi (2004)

The production functions are presented in Table 6:

Table 6. Adjustment coefficients of the adopted production function model

K1	K2	K3	K0	C1	C2	C3
-20.69	1151.9	-	-8481.94	1	0.5	-

Source: Jacomazzi (2004)

5.2.1.3 Climate data

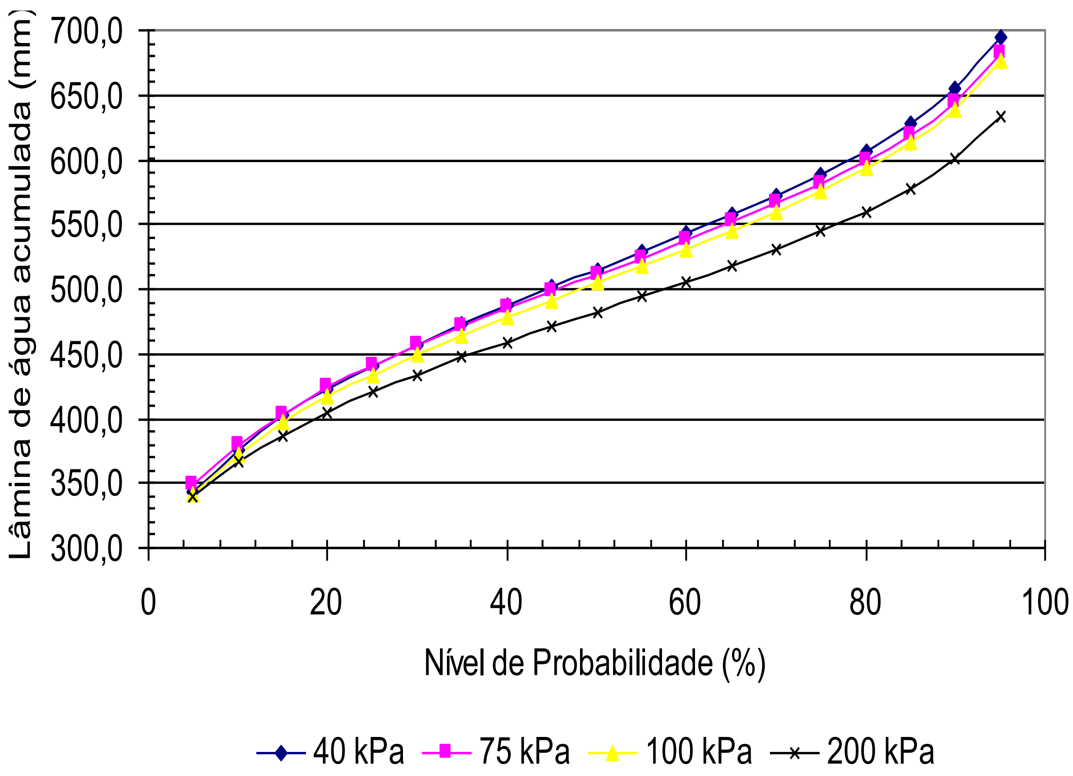
- Region: Piracicaba-SP;
- Historical data series: 45 years;
- Model for estimating potential evapotranspiration: 1st Penman–Monteith (ALLEN et al., 1998; LONGOBARDI; VILLANI, 2013).
- Wind function parameters: a = 1 and b = 0.526;
- Local altitude: 540 m;
- Period considered for estimation: Monthly average (CAPORUSSO; ROLIM, 2015).

Table 4 presents the estimated values of unitary water storage, in mm mm-1, for the total available water capacity (f_CAD) and for the adopted irrigation times (f_IRR).

5.2.2 Results of the application example

Figure 5 shows the expected total depths (rainfall and irrigation), in probabilistic format, for the different irrigation times predefined for the simulation. The normal probability distribution was considered the best fit for the simulated data, according to the Kolmogorov–Smirnov test.

Figure 5. Expected accumulated water depths (rain and irrigation), on a probabilistic basis, for different irrigation times.



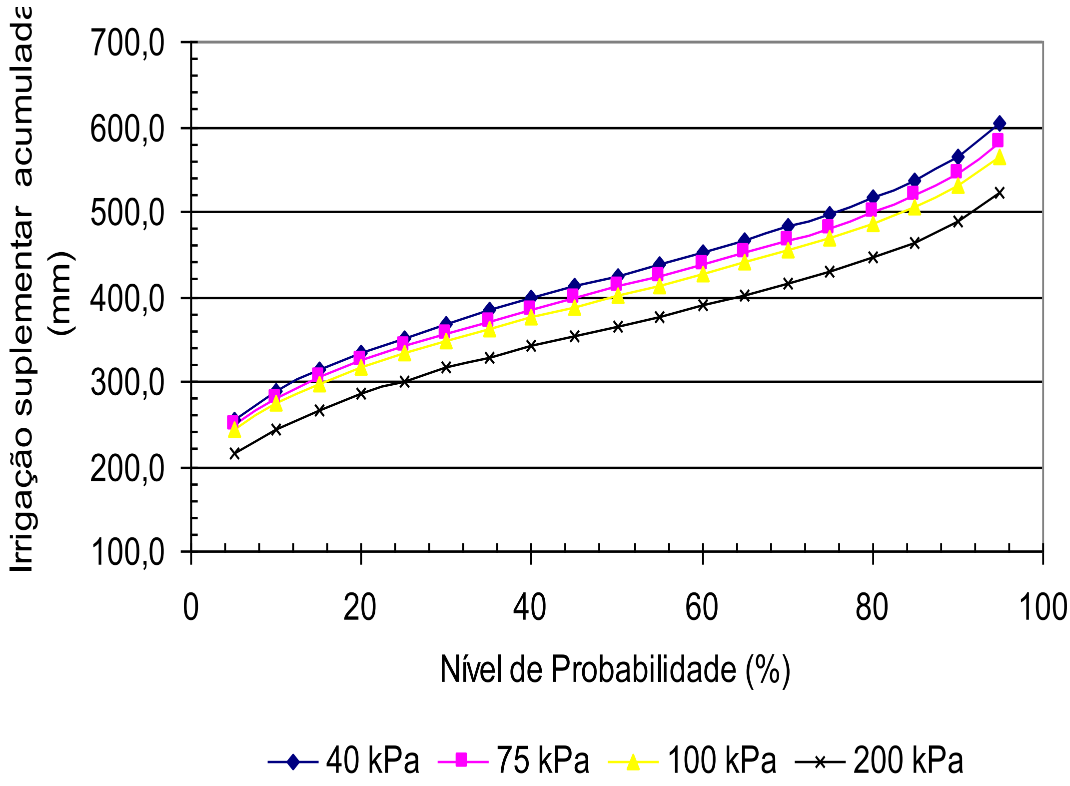
Source: Jacomazzi (2004)

The simulated water depth data indicate that the difference in accumulated water depths between the most frequently irrigated alternative (40 kPa) and the least frequently irrigated alternative (200 kPa) is only 6.0 mm at the 5% probability level (little irrigation). However, this difference increases considerably to 61 mm at the 95% probability level.

Despite a slight increase in the applied depth for the most frequent irrigation times, this variation was insignificant compared with the total amount of water (rain and irrigation), which varied from 350 to 700 mm for the treatment with more frequent irrigation, as was also observed by Prado et al. (2020) when the degree of service increased.

The simulated supplementary irrigation data presented in Figure 6 indicate that the difference in accumulated depths between the most irrigated alternative (40 kPa) and the least irrigated alternative (200 kPa) is 38.3 mm for the 5% probability level and 82 mm for the 95% probability level.

Figure 6. Cumulative supplementary irrigation depths, on a probabilistic basis, for different voltages at the time of irrigation.



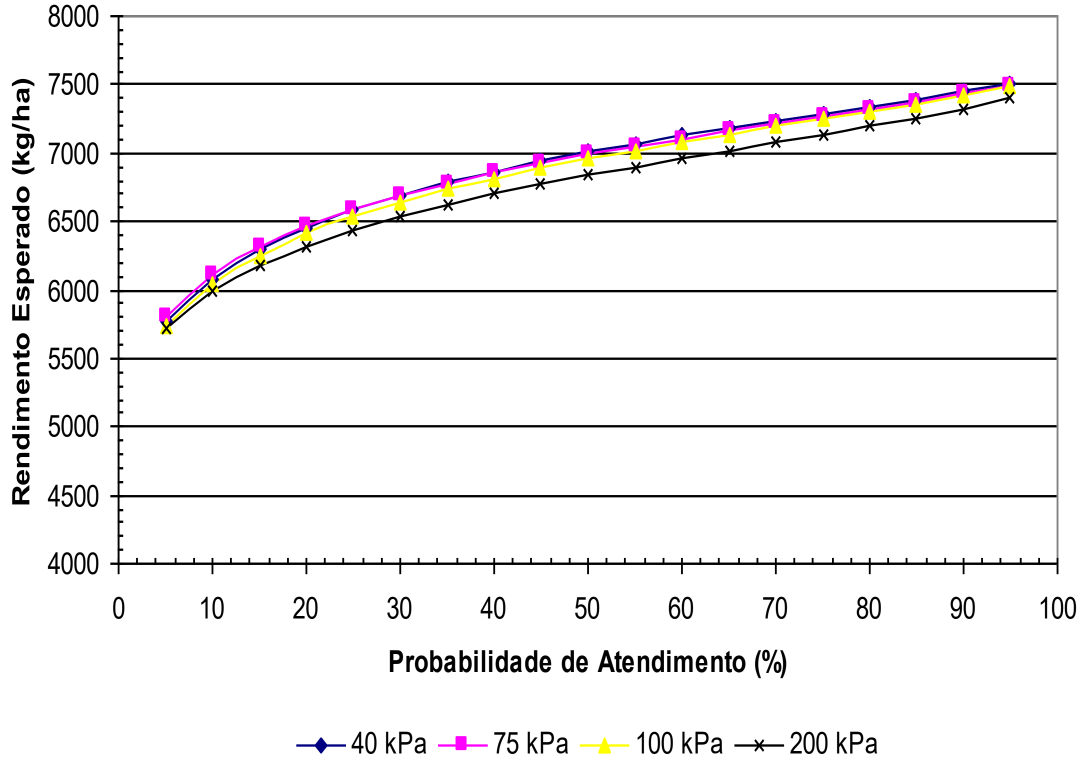
Source: Jacomazzi (2004)

The data presented previously indicate that an increase in the probability of service results in an increase in the applied supplementary irrigation depth (SILVA et al., 2020) and results in a greater difference in the applied irrigation depths for different irrigation voltages.

In general, the irrigation depth varied from 250 to 600 mm per cycle, from the wettest year to the driest year. However, owing to the humid tropical climate of the study region, which has a good rainfall distribution throughout the simulated growing season, the use of supplemental irrigation does not result in significant differences in the water depth applied between the different management levels. This is because the rainfall distribution is sufficient to cover any water deficiencies, even at the end of the cycle, when water deficits tend to be more pronounced in the region (CAPORUSSO; ROLIM, 2015; GURSKI et al., 2021).

On the basis of the simulated probabilistic slides and the adopted production function, Figure 7 was prepared.

Figure 7. Expected yield for "safrinha" corn as a function of probability depth for different durations of irrigation.



Source: Jacomazzi (2004)

On the basis of the simulated yield data, at the 5% probability level, the difference between the most frequent irrigation (40 kPa) and the least frequent irrigation (200 kPa) is 55.5 kg ha -1. For a 95% probability level, the difference in expected average yields between these simulations is 102 kg ha -1. These results are consistent since there is no significant difference in the accumulated depth between the simulations with different frequencies, which provides different levels of water deficit, leading to no significant difference in the expected yields.

With respect to the different years of simulation, the expected productivity varied between approximately 5,750 kg ha -1 and 7,500 kg ha -1, depending on the different probabilities of water supply, highlighting the importance of irrigation practices in the "safrinha" corn crop in Piracicaba, regardless of the frequency of application adopted, as described by Prado et al. (2020).

6 CONCLUSION

The simulation conducted for the Piracicaba region, with irrigated corn planted in late summer, revealed no significant differences between the expected crop yields according to the different management levels adopted. However, differences were observed between the simulations with little or full irrigation.

In regions where the water deficit is not accentuated, that is, where irrigation is only supplementary, the accuracy in determining the fraction of available water that will be used as an indicator for the moment of irrigation is less important than the capacity of the irrigation system to meet the crop's demand.

The variation in the probabilities of meeting crop evapotranspiration through irrigation, which depends on the capacity of the dimensioned system, resulted in irrigation depths that varied from 250 to 600 mm for an autumn cycle in the region.

The application's option to allow the use of various methodologies to calculate reference evapotranspiration makes it suitable for different Brazilian realities, taking into account both climatic conditions and the availability of the information necessary for the program.

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