Validation of the ISAREG model for the irrigation management of the melon crop in the state of Ceará

Kleiton Rocha Saraiva
Instituto Federal de Educação, Ciência e Tecnologia do Piauí, Campus Campo Maior, Piauí, Brazil

Francisco Marcus Lima Bezerra
Universidade Federal do Ceará, Ceará, Brazil

Francisco de Souza
Universidade Federal do Ceará, Ceará, Brazil

Luis de França Camboim Neto
Universidade Federal do Ceará, Ceará, Brazil

Clayton Moura de Carvalho
Instituto Federal de Educação, Ciência e Tecnologia Baiano, Campus Serrinha, Bahia, Brazil

Raimundo Rodrigues Gomes Filho (Corresponding author)
Departamento de Engenharia Agrícola, Universidade Federal de Sergipe, Sergipe, Brazil

Hernandes de Oliveira Feitosa
Instituto Federal de Educação, Ciência e Tecnologia do Piauí, Campus Cocal, Piauí, Brazil

Mário de Oliveira Rebouças Neto
Instituto Federal de Educação, Ciência e Tecnologia do Ceará, Campus Ubajara, Ceará, Brazil

Ketylen Vieira Santos
Departamento de Engenharia Agrícola, Universidade Federal de Sergipe, Sergipe, Brazil

Ralph Wendel Oliveira de Araujo
Universidade Federal do Reconcavo of Bahia, Bahia, Brazil

Abstract

The research aimed to validate the ISAREG model, introducing it to water management studies in irrigation in the State of Ceará, comparing results of experimental research, with results of simulations, carried out with the use of software, analyzing the following variables: crop evapotranspiration, variation of soil water storage and water flow in the soil. A bibliographic survey was carried out to obtain *soil, climate and crop information required by the model to perform the soil water balance. Aiming at the validation of ISAREG, the model was fed with the following data: reference evapotranspiration, precipitation, phenological phases of the crop, effective depth of the root system, water availability factor in the soil, crop coefficient and soil information. Subsequently, the irrigation management option "dates and irrigation depths" was selected, and ISAREG performed the simulation of the soil water balance. The ISAREG demonstrated a detailed soil water balance, being validated in this study, because when its results were compared to the experimental ones, there was similarity in the trends of the variables analyzed, despite the reduced correlation verified regarding the variation of water storage in the soil.*

Keywords: water, water balance, software.

1. Introduction

Globally, irrigated areas account for less than 20% of the total cultivated area of the planet, but produce more than 40% of food, fiber and bioenergetic crops. Despite this enormous importance of irrigated agriculture for humanity, the primordial insum of this production technique, water, a finite and limited resource, has suffered increasing demand, from various origins, in a scenario with few perspectives and visible scarcity (FAO, 2017).

Global food production will have to increase by about 70% by 2050 to meet growing population demand, which will be around 9 billion inhabitants (FAO, 2017). This will consequently result in increased water demand for irrigated agriculture. Moreover, it is not possible to reject the hypothesis that, for Brazil to meet the demands for agricultural products by 2024, it will be necessary to expand productivity and planted area (Saath; Fachinello, 2018). For this, irrigation is a fundamental practice.

In general, in the State of Ceará, as well as in the other States of the Brazilian Northeast, irrigation management is carried out empirically, that is, the irrigator does not know, precisely, how much or when to irrigate (with a view to saving water and energy). Fact corroborated by research already developed in Ceará (Saraiva et al., 2013; Saraiva et al., 2018).

In irrigation, the major problem is low efficiency rates, due to several technical, climatological, soil and crop management factors. Evaporation and leaching losses are considerable. The key word is maximizing the efficiency of water use, increasing its economic income, because in ancient times the sector that will be most affected by the scarcity of resources in quantity and quality will be agricultural (Brito et al., 2012).

An easy to access and effective technique to reduce these problems is the adoption of irrigation calendars, including through the use of computational software. These used in irrigation management calculate crop and irrigation water requirements from climate, soil and crop data. Additionally, the programs allow establishing irrigation schedules for different management conditions, and calculate the water supply scheme of a project for different cultivation patterns (Pereira, 2004).

Several models of simulation of the water balance are precious tools for the determination of irrigation needs and for the conduction of irrigation. The ISAREG model, which is a soil water balance simulation software developed at the Instituto Superior de Agronomia in Portugal, is able to cope with capillary rise and pergrowth through the root zone. ISAREG has been used in several countries and recent applications have been carried out in Brazil (Jobim; Louzada, 2009; Saraiva et al., 2018; Guadagnin et al., 2014; Saraiva et al., 2013).

In turn, studies aimed at validating simulations of computational software applied to irrigation management require the availability of results of careful experiments, carried out under local soil and climate conditions, to analyze variations in soil storage and water flow, according to Chaterlan et al. (2007) one of the main lines of research refers to the development of technologies and the use of well-calibrated models that can contribute to the efficient management of water use.

The research aimed to validate the ISAREG model, introducing it to water management studies in irrigation in the State of Ceará, comparing results of experimental research, previously conducted, with results of simulations, carried out with the use of software, analyzing the following variables: crop evapotranspiration (ETc), total variation of soil water storage (Δh) and soil water flow (q).

2. Material and Methods

To carry out the validation process of ISAREG, a bibliographic survey was carried out, aiming to seek results of research that had all the information of soil, climate and plant, required by the model to perform the soil water balance. This, in order to make differences between the components of the water balance (crop evapotranspiration, soil water flow, and variation in soil water storage) once obtained in field experimentation, with the same components simulated by ISAREG. For this, the results of Carvalho (2006), who researched evapotranspiration and melon cultivation coefficients, in the State of Ceará, using tensiometry and the Class A Tank for soil water balance analysis were used.

Carvalho (2006) counted the water balance in the soil through the irrigation depth, using equation 1 to calculate the crop evapotranspiration.

$$ETc = I + (\pm Qz) - (\pm \Delta h) \quad (1)$$

ETc is the crop evapotranspiration (mm); *I* is irrigation (mm); *Δh* is the variation of soil water storage in the depth layer from zero to Z, for the time interval considered in the balance (mm); and *Qz* is percolation, when negative, or capillary rise, when positive (mm).

The irrigation depths (treatments) of Carvalho (2006) were named according to the evaporated depths in the “Class A” tank (ECA), being: L1 (50% of ECA), L2 (75% of ECA), L3 (100 of ECA) and L4 (150% of ECA). Regarding this research, it is important to mention that in the simulations performed during the validation process the L2 treatment was discarded, as it demonstrated inconsistent results.

The variables obtained by Carvalho (2006) were compared with those obtained through the methodology used by ISAREG in the calculation of these variables, through a statistical analysis of correlation, through its coefficient.

In the calculation of soil water balance, during the simulation, the ISAREG, aiming to simulate the moisture content in the soil, used equation 2.

$$\theta_i = \theta_{i-1} + \frac{(P_i - Q_{ri}) + I_{ni} - ET_{ci} - DP_i + GW_i}{1000 Z_{ri}}$$

(2)

θ_i - soil water content in the root zone (m^3 m^{-3} or mm mm^{-1}) on day *i*; θ_{i-1} - soil water content in the root zone on day *i-1* ($m^3.m^{-3}$); P_i - precipitation on day *i* (mm); $Q_{r\,i}$ - surface runoff on day *i* (mm); $I_{n\,i}$ - irrigation (liquid) depth on day *i* (mm), i.e. the amount of irrigation water which actually infiltrated for storage in the root zone; $ET_{c\,i}$ - culture evapotranspiration on day *i* (mm); DP_i - percolation on day *i* (mm); and GW_i - accumulated flow of capillary rise on day *i* (mm).

In obtaining the current soil moisture, for the calculation of the water balance, the following observational steps below were followed. ISAREG used the following methodology indicated by Pereira (2004):

The amount of total available water in the soil (TAW) resulted from equation 3.

$$TAW = 1000(\theta_{FC} - \theta_{WP})Z_r \quad (3)$$

TAW - total available water in the root area (mm); θ_{FC} - soil water content at field capacity ($m^3.m^{-3}$); θ_{WP} - soil water content at wilting point ($m^3.m^{-3}$); and Z_r - root depth, i.e. of the area explored by the roots (m).

To perform the water balance, values related to soil moisture content were used. Thus, the fraction of the water of the extractable soil was used without affecting the production (p) that allowed the calculating of the easily available water (*RAW2*), through equation 4.

$$RAW = p\,TAW = p\,1000(\theta_{FC} - \theta_{WP})Z_r$$

(4)

RAW^2 - soil water easily available in the root zone (mm); p - fraction of the water from the extracted soil without affecting the production, that is, it is the fraction of TAW that can be extracted from the root zone without water stress; TAW - total available water in the root area (mm); θ_{FC} - soil water content at field capacity ($m^3.m^{-3}$); θ_{WP} - soil water content at wilting point ($m^3.m^{-3}$); and Z_r - depth of the zone explored by the roots (m).

At the time of the research capillary ascent was despised. According to Pereira (2004) there are no problems in not using this variable in the water balance since its value is relatively small when compared to the ETc and with the precipitation and irrigation depths, being frequently lower than the error that is made in the calculation of the water balance.

As for percolation, ISAREG used the following criteria:

$$DP_i = 0 \quad \text{when } \theta_i \leq \theta_{FC}$$

$$DP_i = 1000(\theta_i - \theta_{FC})Z_{rI} \quad \text{when } \theta_i > \theta_{FC}$$

During the simulation process, the following information was required: the cycle of the same, with its well-defined phenological phases (6 phases), the depth of the root system (z), each phenological phase, the water availability factor (p), also by phenological phase, and the crop coefficient (Kc), in 3 (three) stages (initial, medium and final).

Another variable demanded by ISAREG was the coefficient of sensitivity of production to water stress (Ky), but since there was no information about this coefficient in the selected research, the model was not fed with this information.

The values of "z" were 0.1 and 0.2 m in the first two phenological phases of the melon crop, and 0.4 m in the remaining phases. Due to the lack of scientific information, "p" was considered 0.2 for all phenological phases of the culture. The Kc varied for each treatment elaborated by Carvalho (2006), because for L1 it varied from 0.29 to 0.86; for L3 it was 0.54 to 0.89 and for L4 the Kc's ranged from 0.37 in the initial phase to 1.00 in the phases of greater water demand of the melon culture.

Regarding climate data, ISAREG was fed with reference evapotranspiration (ETo) values, obtained through the methodology adopted by Carvalho (2006). The model was also fed with precipitation data. However, during the field experiment there was no precipitation. The average monthly ETo during the crop cycle was 5.1 mm.

As for the soil data, the field capacity and the permanent wilting point were used, in volume fraction, at each soil layer considered in the field experiment. In the 0-20 cm layer the field capacity and the wilting point were 0.19 m and 0.06 m, respectively. In the 20-40 cm layer these values were, in the same order, 0.18 m and 0.07 m.

In the case of the irrigation management option, at the time of simulation, it was decided to feed the model with information about the dates and blades in which Carvalho (2006) irrigated the melon crop, for each treatment, differently. However, it is worth noting that the model has the limitation of processing only thirty (30) irrigation observations. But as the melon cycle of the field experiment was 60 days, and irrigation was performed daily, it would be necessary for ISAREG to process sixty (60) irrigation observations. To alleviate this limitation, during the simulation, the 60 observations were transformed into 30, taking care to maintain the total blade applied per treatment during the field experiment. In the case of treatment L1, the slats varied from 5.0 mm to 17.3 mm. In L3 these slates ranged from 15.6 mm to 37.9 mm, and in L4 the values were minimum 21.8 mm and maximum 57 mm.

In the validation process the estimated values of the following water balance variables: variation of water storage in the soil (Δh), water flow in the soil (q), and crop evapotranspiration (ETc), through the ISAREG model were correlated with the observed data (field experiment - (Carvalho, 2006)), through the statistical indicators: precision, given by the correlation coefficient "r" (Allen et al., 1998); accuracy or agreement, through Willmott's agreement index "d" (Willmott et al., 1995) and performance or confidence "c" (Camargo; Sentelhas, 1997), where Pi is the estimated value, Oi the observed value and O the average of the observed values. Equations 5, 6 and 7 represent the correlation, accuracy and performance indices, being respectively the following:

$$r = \frac{\sum_{i=1}^{N}(O_i - O)(P_i - P)}{\sqrt{\sum_{i=1}^{N}(O_i - O)^2 \sum_{i=1}^{n}(P_i - P)^2}} \quad (5)$$

$$d = 1 - \left[\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{N}|P_i - O|^2 + |O_i - O|^2}\right] \quad (6)$$

$$c = d\ x\ r \quad (7)$$

Accuracy is given by the correlation coefficient that indicates the degree of dispersion of the data obtained in relation to the mean, that is, the random error. The accuracy is related to the distance of the estimated values in relation to the observed ones, whose values vary from zero, for no agreement, to 1, for perfect agreement. The performance or confidence index "c", proposed by Camargo and Sentelhas (1997), is obtained by the product between the correlation coefficient (r) and the Willmott index (d) and interpreted according to these authors as: "excellent" (c > 0.85); "very good" (c between 0.76 and 0.85); "good" (c between 0.66 and 0.75); "average" (c between 0.61 and 0.65), "poor" (c between 0.51 and 0.60), "bad" (c between 0.41 and 0.50) and "terrible" (c < 0.40) (Pereira et al., 2009).

3. Results and Discussion

Aiming at a more accurate and conclusive analysis of the ISAREG validation process, a comparison between experimental results (Carvalho, 2006) and simulations using the ISAREG model. The Comparison of crop evapotranspiration obtained by the ISAREG model and the study of Carvalho (2006) was made (Figura 1).

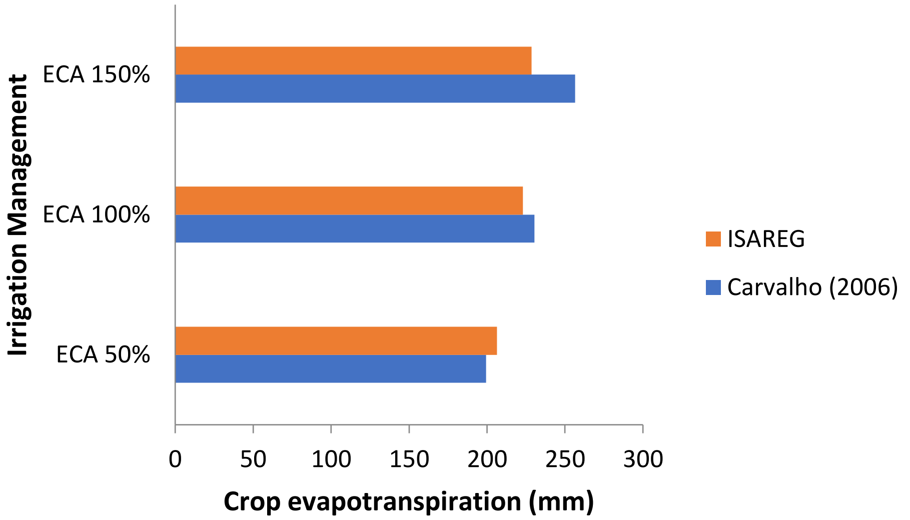

Figure 1. Comparison of crop evapotranspiration obtained by the ISAREG model and the study of Carvalho (2006).

ECA - Evaporation of "Class A" tank.

By analyzing Figure 1 it can be seen that for the irrigation management condition of 50% of ECA, the total evapotranspiration for the crop cycle calculated experimentally (199.5 mm) was close to the ETc simulated by ISAREG (206.3 mm). In this case the simulated ETc overestimated the experimental ETc by 3.3%. This behavior is probably due to the issue of irrigation shift, at the moment of simulation, which was 2 days (model limitation), differently from the experimental one, which was 1 day. A similar percentage variation was verified by Guadagnin et al. (2014), during the validation process of ISAREG.

For the management conditions of 100% and 150% of ECA, also the total evapotranspirations were close, because for the 100% condition the simulated ETc underestimated the experimental ETc by 3.2%, and for the 150% condition, the simulated ETc underestimated the experimental ETc by 10.9%. These differences, although acceptable, can be justified due to the six (6) crop development phases that ISAREG requires to allocate the Kc values.

In comparing the experimental and simulated results, the performance of ISAREG with respect to ETc was also evaluated using the statistical indicators: precision, accuracy, and performance (Table 1).

Table 1. Precision (*r*), accuracy (*d*) and performance (*c*) calculated for the relationship between the values

of Crop Evapotranspiration (ETc) simulated by the ISAREG model and measured by tensiometers in the experiment of Carvalho (2006)

Statistics	Value
r	0.971
d	0.750
c	0.730

The high value of the correlation coefficient obtained in the evaluation indicates the small degree of dispersion of the data in relation to the mean; the agreement index revealed the good accuracy of the model; and the value of the performance indicator, obtained in the evaluation classifies the model as "good", according to the scale proposed by Camargo and Sentelhas (1997). Also, Jobim and Louzada (2009), in an evaluative research carried out in Rio Grande do Sul, they verified that the ISAREG model satisfactorily simulated the soil water balance, validating its use.

According to Rivera and Ulloa (2007), despite the advances made, when climatic information is needed to determine crop evapotranspiration, it is possible to warn that in many locations there are drawbacks, such as lack of data, inadequate spatial distribution, and low quality of records, as well as a lack of unified criteria for the selection of stations and estimation of climatic variables.

The Comparison of total variation of water storage in the soil obtained by the ISAREG model and the study of Carvalho (2006) was made (Figura 2).

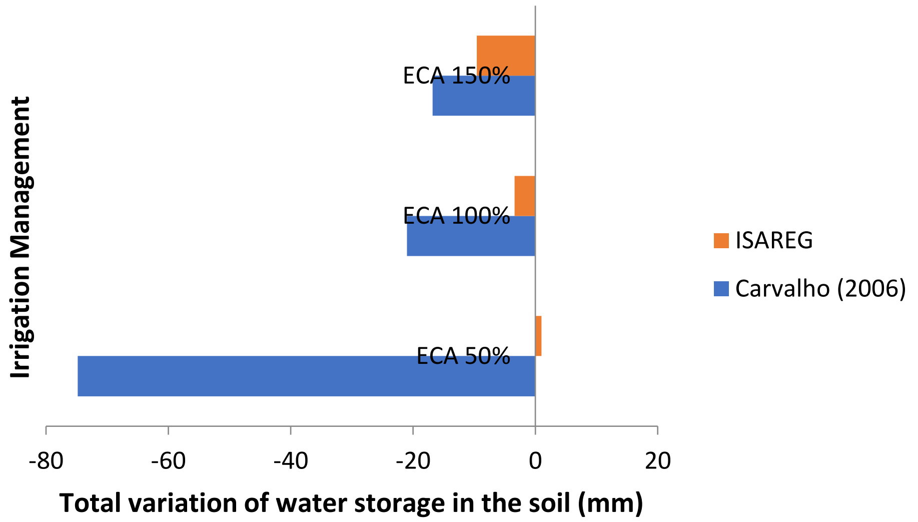

Figure 2. Comparison of total variation of water storage in the soil obtained by the ISAREG model and the study of Carvalho (2006).

For the 100% ECA condition, the variation of soil water storage (*Δh*) simulated by the model overestimated the experimental *Δh* by 83.8%. For the 150% condition, the overestimation of the simulated *Δh* over the experimental Δh was 42.9%. This event is probably due to the same reason as the irrigation shift was 2 days during the simulation, differing from the experimental irrigation shift, which was 1 day. However, the gradual increase observed between the irrigation management conditions is justified by the fact that ISAREG processes, in view of the physical characteristics of the soil (provided in the simulation), that with the increase of the shift and the increase of the applied blade, the greater the water storage in the soil will be.

According to Pereira (2004) the variation of water storage in the soil depends directly on the soil thickness and the depth of the root system, i.e. the vertical flow of water in the soil may not be correctly accounted for by the model if there is imprecise information regarding the variables required by ISAREG.

Furthermore, the experimental irrigation rates of Carvalho (2006), used to validate the ISAREG model, were not based on the readings of the installed tensiometers, to control how much to irrigate (control of irrigation rates), but on the information from the “Class A” Tank. As a consequence, the applied slopes could be higher or lower than the variation of water storage in the soil, which altered the results of the water balance, measured and simulated, as statistically verified.

Therefore, as some values demanded by the model could not be provided accurately, it may have caused these differences in the values of Δh. It is so much so that Chaterlan et al. (2007) calibrated and validated ISAREG, using the onion crop in Alquizar - Cuba. To do so, they analyzed 20 years of accurate crop data to determine the crop coefficient and the soil water availability factor, observing these variables in all phenological phases of the crop. Moreover, according to Carlesso and Pereira (2008), during the validation of ISAREG the data required should be accurate, and they exemplify a validation case in Portugal, where 4 years of research were needed to generate the data required for the model validation process.

In comparing the experimental and simulated results, the performance of ISAREG with respect to the total variation in soil water storage (Δh) was also evaluated using the statistical indicators: precision, accuracy, and performance (Table 2).

Table 2. Precision (r), accuracy (d) and performance (c) calculated for the relationship between the values of total variation in soil water storage (Δh) simulated by the ISAREG model and measured by tensiometers in the experiment of Carvalho (2006).

Statistics	Value
r	- 0.849
d	0.430
c	- 0.360

The negative value of the correlation coefficient obtained in the evaluation indicates the great degree of dispersion of the data in relation to the mean; the agreement index revealed low model accuracy; and the value of the performance indicator, obtained in the evaluation classifies the model as "poor", according to the scale proposed by Camargo and Sentelhas (1997).

Probably, these results were due to the model's limitation in only accepting 30 irrigation inputs, the values simulated by ISAREG distanced themselves, because it was clear that when the irrigation frequency is modified, the soil water storage behavior also changes, but in a contrary way to the crop evapotranspiration.

Also, as explained above, these results for the variable Δh may have occurred due to the lack of precision during the "feeding" of the data required by ISAREG, such as information divided into six (6) phenological phases of the crop; soil data; and/or due to the blades applied by Carvalho (2006) perhaps being larger or smaller than the variation of water storage in the soil, which may have altered the results of the water balance, when compared after the model simulation. Pereira (2004) states that in the validation of models like ISAREG, the curves should follow the same trend, but it is important to say that discrepancies in the experimental results can affect the validation, that is, ISAREG can generate inaccurate information due to the lack of precision in the data provided. Complementing this, according to Jemai et al. (2013) physical and hydric aspects of the soil can alter the storage and dynamics of water in the soil.

In Figure 3 it can be seen that for the irrigation management condition of 50% ECA, the soil water flow obtained experimentally (-14.2 mm) was higher than the simulated one, which showed "zero". In this case ISAREG "revealed" that there was no excess water, as well as the crop suffered water deficit during the entire cycle. For the 100% ECA condition the simulated flux underestimated the experimental by 13.9%, but for 150% ECA the simulated flux overestimated the experimental by 9.2%.

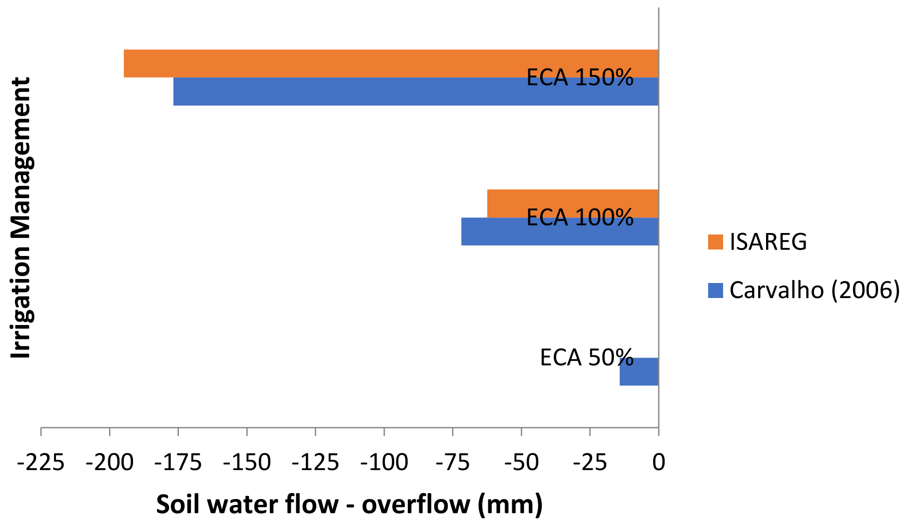

Figure 3. Comparison of soil water flow obtained by the ISAREG model and the study of Carvalho (2006).

In the soil water flow analysis, it was concluded that the differences for each management condition were quite small, compared to those observed in the study of the variation of water storage in the soil and crop evapotranspiration. Similarly, during research conducted in China for the validation of ISAREG, small differences in the results of analyzed variables (simulation versus field observations) were verified by Cai et al. (2009).

Carvalho (2006) did not use tensiometers to determine the moment of irrigation, because the control of the irrigation depth was from the "Class A" Tank, that is, two different methodologies for irrigation management. During the validation process, the simulated information may differ from that observed in the field (experimental) due to this fact. It is a fact that estimating evapotranspiration through evaporimetric tanks is risky, because it shows low accuracy and the measurements cause accumulated estimates of evapotranspiration that are often unrealistic (Carlesso; Pereira, 2008).

In comparing the experimental and simulated results, the performance of ISAREG with respect to soil water flow was also evaluated using the statistical indicators: precision, accuracy, and performance (Table 3).

Table 3. Precision (*r*), accuracy (*d*) and performance (*c*) calculated for the relationship between the values of soil water flow simulated by the ISAREG model and measured by tensiometers in the experiment of Carvalho (2006)

Statistics	Value
r	0.999
d	0.998
c	0.997

The high value of the correlation coefficient obtained in the evaluation indicates the small degree of dispersion of the data in relation to the mean; the agreement index revealed the excellent accuracy of the model and the value of the performance indicator, obtained in the evaluation classifies the model as "excellent", according to the scale proposed by Camargo and Sentelhas (1997). The accuracy of mathematical models, as is the case of ISAREG, during irrigation management calculations is high when soil and climate data are of good quality (Guadagnin, 2013).

Corroborating this, Guadagnin et al. (2014) when conducting research with the ISAREG model, aiming to validate it for use in Santa Catarina, they concluded that the model satisfactorily simulates the soil water balance. Similarly, ISAREG was calibrated and validated during research conducted by Wu et al. (2012) in China, through observations of water content in the soil.

The ISAREG model was efficient when analyzing the total water flow values, because it is not by chance that for Rivera and Ulloa (2007) ISAREG is one of the main simulation models to calculate soil water flow, enabling the generation of irrigation alternatives, collaborating to reduce the impacts related to crop yields.

4. Conclusions

The ISAREG model demonstrated a detailed soil water balance, when scientifically analyzing the variables studied, because when its results were compared to the experimental ones, there were similarities in the trends of the variables analyzed (crop evapotranspiration, total variation in soil water storage and soil water flow). However, it is worth pointing out that the disparities verified are due to the imprecision of the data required for the simulations, since the experiments performed in the field had not been designed with the main objective of validating models, but to generate Kc values.

The ISAREG model was validated, because although there were significant differences, between the experimental results and the total simulated ones, regarding the variable: variation of water storage in the soil (Δh), the results of crop evapotranspiration (ETc) and soil water flow (q), during the validation process, proved to be acceptable, for it is worth pointing out that although ISAREG is an important tool in irrigation management, its precise use becomes difficult, due to the lack of data and basic technical-scientific information, required by the model during its simulation.

5. References

Allen, R., Pereira, L.S., Raes, D., Smith, M. (1998). Crop Evaporation. Guidelines for computing crop water requirements. FAO Irrigation and drainage. Paper n.56, FAO, Rome.

Brito, R.R., Gomes, E.R., Ludwig, R. (2012). Uso da água na irrigação. Fórum Ambiental da Alta Paulista, 8(2):373-383.

Cai, J.B., Liu, Y., Xu, D., Paredes, P., Pereira, L.S. (2009). Simulation of the soil water balance of wheat using daily weather forecast messages to estimate the reference evapotranspiration. Hydrol. Earth Syst. Sci., 13:1045–1059.

Camargo, A.P., Sentelhas, P.C. (1997). Avaliação do desempenho de diferentes métodos de estimativas da evapotranspiração potencial no Estado de São Paulo, Brasil. Rev. Bras. de Agrometeorologia, Santa Maria, 5(1):89–97.

Carlesso, R., Pereira, L.S. (2008). Jornadas sobre "Ambiente y Riegos: Modernización y Ambientalidad", Red Riegos, CYTED y AECID. Necessidades de água dos cultivos: uso de modelos para a programação e manejo da rega; aplicação a casos reais com enfoque nos impactos ambientais. La Antigua (Guatemala).

Carvalho, L.C.C. (2006). Evapotranspiração e coeficientes de cultivo do melão sob diferentes lâminas de irrigação. Dissertação de Mestrado. Fortaleza-Ce. 2006, 73p.

Chaterlan, Y., Duarte, C., León, M., Pereira, L.S., Teodoro, P.R., García, R.R. (2007). Coeficientes de cultivo de la cebolla y su determinación con el modelo ISAREG. In: Modernización de Riegos y uso de Tecnologías de Información (Red CYTED-Riegos, La Paz, Bolivia, Setembro de 2007). Anais... La Paz, Bolívia CD-ROM.

FAO – Organização das Nações Unidas para a Alimentação e a Agricultura. (2017). Agricultura Irrigada Sustentável no Brasil: identificação de áreas prioritárias. Brasília. 243p.

Guadagnin, C.A., Tavares, V.E.Q., Timm, L.C. (2014). Validação do modelo isareg para simulação do balanço hídrico em cambissolos do extremo oeste de Santa Catarina. Anais... XIV ENPOS. 4f.

Guadagnin, C.A. (2013). Avaliação de cenários hidroagrícolas em sistemas de produção de base familiar na região do Extremo Oeste Catarinense (Tese de Doutorado). Universidade Federal de Pelotas. 88f. Pelotas.

Jobim, C.I., Louzada, J.A.S. (2009). Avaliação de desempenho do modelo ISAREG de simulação de balanço hídrico. Pesquisa Agropecuária Gaúcha, Porto Alegre, 15(2):91-98.

Jemai, I., Ben Aissa, N., Ben Guirat, S., Ben-Hammouda, M., Gallali, T. (2013). Impact of three and seven years of no-tillage on the soil water storage, in the plant root zone, under a dry subhumid Tunisian climate. Soil & Tillage Research, Amsterdam, 126:26-33.

Pereira, D.R., Yanagi, N.M., Mello, C.R., Silva, A.M., Silva, L.A. (2009). Desempenho de métodos de estimativa da evapotranspiração de referência para a região da Serra da Mantiqueira, MG. Ciência Rural, 39(9):2488-2493. https://doi.org/10.1590/S0103-84782009000900016

Pereira, L.S. (2004). Necessidades de Água e Métodos de Rega. Publ. Europa-América, Lisboa, 313 p.

Pereira, L.S. (2007). Necessidades de água e programação da rega: modelação, avanços e tendências. Taller Internacional: Modernización de riegos y uso de tecnologias de información. La paz – Bolivia.

Rivera, R.C., Ulloa, A.O. (2007). Necesidades de água y programación de riegos: avances basados em nuevas tecnologías de la información. Bolívia. p. 09-13.

Saath, K.C.O., Fachinello, A.L. (2018) Crescimento da Demanda Mundial de Alimentos e Restrições do Fator Terra no Brasil. RESR, Piracicaba-SP, 56(2):195-212.

Saraiva, K.R., Bezerra, F.M.L., Souza, F., Camboim Neto, L.F. (2013). Aplicação do "ISAREG" no manejo da irrigação na cultura da melancia no Baixo Acaraú, Ceará. Revista Ciência Agronômica, 44(1):53-60.

Saraiva, K.R., Viana, T.V.A., Costa, S.C., Bezerra, F.M.L., Carvalho, C.M., Gomes Filho, R.R. (2018). Interactive Effect of Soil Mulching and ISAREG Model Based Irrigation on Watermelon Production. JEAI - Journal of Experimental Agriculture International, 24(5):1-13.

Willmott, C.J., Ackleson, S.G., Davis, R.E., Feddema, J.J., Klink, K.M., Legates, D.R., Rowe, C.M., O'Donnell, J. (1995). Statistics for the evaluation and comparison of models. Journal of Geophysical Research, Ottawa, 90(5):8995-9005.

Wu, Y., Liu, T., Pereira, L.S., Paredes, P., Wang, H. (2012). Validation and Application of Model ISAREG in a Typical Semiarid Sand-Meadow Area of Horqin Sandy Land. 6th Computer and Computing Technologies in Agriculture (CCTA), Oct 2012, Zhangjiajie, China. 421-429.