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# A smartphone APP for weather-based irrigation scheduling using artificial neural networks

**Abstract** – The objective of this work was to develop a smartphone application (APP) for a weather-based irrigation scheduling using artificial neural networks (ANNs), as well as to validate it in a green corn (*Zea mays*) crop. An APP (IrriMobile) that uses ANNs based on temperature and relative humidity, or on temperature only, was developed to estimate the reference evapotranspiration ($ET_o$). The APP and Bernardo's methodology for irrigation scheduling, with the $ET_o$ estimated by the FAO-56 Penman-Monteith equation, were used to schedule the irrigation for a green corn crop. The performance of empirical equations to estimate $ET_o$ was also assessed. Several corn morphological and agronomic characteristics were evaluated. The APP was used in the experiment with temperature, relative humidity, and rainfall data. Its use was also simulated with temperature and rainfall data only. There was no difference for any of the green corn characteristics evaluated. $ET_o$ estimation through the APP showed a higher performance than that by the evaluated equations. The APP overestimates the irrigation requirements by 8 and 19% when using temperature and relative humidity, and temperature only, respectively.

**Index terms**: *Zea mays*, artificial intelligence, evapotranspiration, machine learning, smart irrigation.

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## Aplicativo de celular para manejo da irrigação com base no clima por meio de redes neurais artificiais

**Resumo** – O objetivo deste trabalho foi desenvolver um aplicativo (APP) para manejo da irrigação com base no clima, por meio de redes neurais artificiais (ANNs), além de validá-lo em um cultivo de milho (*Zea mays*) verde. Desenvolveu-se um APP (IrriMobile) que utiliza ANNs com base em temperatura e umidade relativa, ou apenas em temperatura, para estimar a evapotranspiração de referência ($ET_o$). O aplicativo e a metodologia de manejo da irrigação de Bernardo, com a $ET_o$ estimada pela equação FAO-56 Penman-Monteith, foram utilizados para manejar a irrigação na cultura do milho verde. Avaliou-se também o desempenho de equações empíricas para estimar a $ET_o$. Avaliaram-se diversas características morfológicas e agronômicas do milho. O APP foi utilizado no experimento com dados de temperatura, umidade relativa e precipitação. Simulou-se, também, seu uso apenas com dados de temperatura e precipitação. Não houve diferença para nenhuma das características do milho avaliadas. A estimação de $ET_o$ pelo APP mostrou desempenho superior à das equações avaliadas. O aplicativo superestima os requisitos de irrigação em 8 e 19%, ao usar temperatura e umidade relativa, e apenas temperatura, respectivamente.

**Termos para indexação**: *Zea mays*, inteligência artificial, evapotranspiração, aprendizado de máquina, irrigação inteligente.

## Introduction

Irrigation is a strategy of great importance for agriculture, making production feasible in areas of low rainfall, and increasing the guarantee of good yields in areas of high rainfall. In addition, irrigation results in a substantial yield increase, reducing the need for the expansion of the cultivated area (ANA, 2016). According to the national water agency (ANA, 2017), Brazil had an irrigated area of almost seven million hectares in 2015.

Despite its benefits, irrigation requires a high-water consumption. In this context, irrigation scheduling represents an important strategy for the adequate use of water. For an effective adoption of irrigation scheduling by farmers, it is necessary to use tools that facilitate this task, such as computer, or smartphone programs. However, in Brazil, there are not sufficient applications developed for smartphones that can be used by farmers in general.

Weather-based irrigation scheduling is one of the methods most commonly used (Allen et al., 1998; Bernardo et al., 2006; Ballesteros et al., 2016). To use this kind of scheduling, it is necessary to estimate the reference evapotranspiration ($ET_o$) from meteorological data. With the $ET_o$, it is possible to estimate the crop-water demand. Several equations for $ET_o$ estimation have been proposed. The FAO-56 Penman-Monteith (FAO-56 PM) equation is considered as a standard method by the Food and Agriculture Organization (FAO) (Allen et al., 1998). This equation, although presenting good accuracy, has the disadvantage of requiring several meteorological variables (temperature, relative humidity, solar radiation, and wind speed), which makes it difficult to use in cases in which these data are not fully available (Ballesteros et al., 2016).

As an alternative to the FAO-56 PM equation, it is possible to estimate $ET_o$ under a limited availability of meteorological data, using artificial neural networks (ANNs) (Kumar et al., 2011; Yassin et al., 2016; Ferreira et al., 2019). ANN is a mathematical model with an architecture analogous to the learning ability of the human brain, where interconnected processing elements are arranged in layers (Kumar et al., 2011). ANNs have a high potential for modeling complex problems, such as $ET_o$. Thus, this technique exhibits, in general, a superior performance to conventional equations for the estimation of $ET_o$ (Kumar et al., 2011; Ferreira et al., 2019).

Recently, Ferreira et al. (2019) developed ANNs to estimate $ET_o$ in Brazil, using temperature and relative humidity, or only temperature. The ANN models show higher performances than the traditionally used equations. In addition, in the abovementioned study, two strategies improved the performance of the ANN models, as follows: the definition of climatically homogeneous regions, using the K-means algorithm with the development of specific ANN models for each region; and the use of meteorological data from previous days as input to ANNs. Promising results were found with the ANN models developed, using data from four previous days, in addition to the data from the current day.

Most studies using ANNs to estimate $ET_o$ remain only in the theoretical field. Thus, the development of practical solutions, such as smartphone APPs, using ANNs, represents an important step to make this technology accessible to farmers.

The objective of this work was to develop a smartphone APP for irrigation scheduling in Brazil, using ANNs, as well as to validate the APP on a green corn crop.

## Materials and Methods

A smartphone APP, named IrriMobile, was developed for the Android platform. In this APP, users can register a farm and the farm areas which will be irrigated. To register a farm, only its name and location (state and municipality) are requested. Based on this information, IrriMobile automatically accesses the farm latitude, since it is used to estimate the $ET_o$. To register an area, the following information are required: on the cultivation – crop, planting date, average length of the growing cycle, and area shaded by the crop (only for microirrigation systems); on the irrigation system – system, application intensity and wetted area (only for microirrigation systems); and soil – field capacity (FC), permanent wilting point (PWP), and bulk density (BD). The information on the area shaded by the crop, which is required when using microirrigation, can be edited at any time by the user because of the variation of this variable over time.

The following irrigation systems are available: overhead sprinkler, micro sprinkler, drip irrigation, and center pivot.

After registering the farm and area to be managed, it is necessary to provide daily meteorological data measured in the previous day. For this, there are two options: maximum and minimum air temperatures and rainfall; or maximum and minimum air temperatures, mean relative humidity, and rainfall. From these data, the IrriMobile performs several processes that result in information on the irrigation time/amount and soil-water content. These processes can be divided into four steps: estimation of $ET_o$, estimation of crop evapotranspiration ($ET_c$), soil-water balance, and calculation of irrigation time.

The $ET_o$ estimation can be done using the maximum and minimum temperatures and mean relative humidity, or only the maximum and minimum temperatures. For this estimation, the APP uses the ANNs obtained by Ferreira et al. (2019). ANNs developed considering the use input data from four previous days, in addition to data of the current day, are used. The ANN models also use extraterrestrial radiation as input (automatically calculated with basis on latitude and day of the year). More details on the ANNs used can be seen in Ferreira et al. (2019). On the first day of the irrigation scheduling, due to data unavailability of previous days, the APP uses ANN models that do not require such data. From the second to the fourth day, ANN models with data from one previous day are used. From the fifth day onwards, ANN models with data from four previous days are used.

$ET_c$ is calculated using Equation 1, as recommended by Bernardo et al. (2006), as follows:

$$ET_c = ET_O * Kc * Ks * Kl \quad (1),$$

in which: $ET_o$ is the reference evapotranspiration (mm $d^{-1}$); Kc is the crop coefficient; Ks is the water-stress coefficient; Kl is the localization coefficient.

Crop coefficient (Kc) values are already inside the APP's original database. Kc value is automatically chosen with basis on the crop, number of days after sowing, or planting, and on the average length of the growing cycle (previously informed in the farm/area register). Water-stress coefficient (Ks) is calculated according to the Equation 2, as follows:

$$Ks = \frac{\ln(SWC + 1)}{\ln(TAW + 1)} \quad (2),$$

in which SWC is the soil-water content (mm); TAW is the total available water (mm);

$$TAW = \frac{(FC - PWP)}{10} * BD * z \quad (3),$$

in which: FC is the field capacity (%) (water mass over dry soil mass); PWP is the permanent wilting point (%) (water mass over dry soil mass); BD is the soil bulk density (g $cm^{-3}$); z is the effective rooting depth (cm).

The parameters FC, PWP, and BD are accessed from the data registered by the user. The effective rooting depth (z) is defined by the APP based on the crop and its development phase. For the TAW calculation in microirrigation systems, the TAW value obtained using the Equation 3 is multiplied by the percentage of wetted area (decimal). This is done because the water lost due to evapotranspiration is extracted only from the wetted part of the cultivated area.

The localization coefficient (Kl) is calculated according to the Equation 4, as follows:

$$Kl = 0.1\sqrt{P} \quad (4),$$

in which: P is the highest value between the area shaded by the crop and the area wetted by the irrigation system (%).

After the steps above mentioned, the soil-water balance is computed, taking into account the inputs (rainfall and irrigation) and the output ($ET_c$) of water. For this, the Equation 5 is used, as follows:

$$SWC_i = SWC_{i-1} - ET_c + P + (I * Ie) \quad (5),$$

in which: $SWC_i$ is the soil-water content on the current day (mm); $SWC_{i-1}$ is the soil-water content on the previous day (mm); $ET_c$ is the crop evapotranspiration (mm $d^{-1}$); P is the effective rainfall (mm); I is the irrigation depth (mm); Ie is the irrigation efficiency (decimal).

It should be mentioned that on the first day of irrigation scheduling, the soil is considered to be at field capacity, and soil-water content equals TAW. User should inform the water depth applied by the irrigation system. Irrigation efficiency (Ie) is automatically set as a default value, according to the irrigation system chosen by the user. The following Ie default values are used: overhead sprinkler, 80%; microsprinkler, 90%; drip irrigation, 90%; center pivot (spray), 85%; and center pivot (low-energy precision application - LEPA), 90%. Regarding rainfall, the effective rainfall (rainfall stored in the root zone) is considered equal to the total rainfall until it does not cause soil-water content higher than field capacity.

Finally, the irrigation time required for soil to return to FC is calculated using Equation 6, as follows:

$$It = \frac{TAW - SWC}{Ie * Ai} \quad (6),$$

in which: It is the irrigation time (h); TAW is the total available water (mm); SWC is the soil-water content (mm); Ie is the irrigation efficiency (decimal); Ai is the application intensity (mm $h^{-1}$).

The IrriMobile also assists users for the best moment to apply the irrigation water. For this procedure, a soil-water content range, in which the plant does not undergo water stress, is indicated. This water-content range represents the readily available water (RAW), which is calculated according to the Equation 7 below. Soil-water depletion fraction for no stress (p) is automatically obtained by the APP according to the crop, as follows:

$$RAW = TAW * p \quad (7),$$

in which: RAW is the readily available water (mm); TAW is the total available water (mm); p is the soil-water depletion fraction for no stress.

After the steps above mentioned, the required irrigation time and the current soil-water content are displayed. The user can apply the recommended irrigation depth, or choose to not irrigate, or apply a different irrigation depth. From the irrigation time chosen by the user, the APP recalculates the soil-water balance and saves the current soil-water content.

The available crops and their Kc, p, and z values, as well as the relative duration of their growth stages: initial (phase 1), crop development (phase 2), mid-season (phase 3), and late season (phase 4) are presented (Table 1). The values were selected with basis on the FAO Bulletin 56 (Allen et al., 1998). The duration in days of each growth phase is calculated based on the average length of the growing cycle informed by the user. Kc values vary according to the crop growth stages; the z value remains constant during phase 1, increasing linearly during phase 2 up to its maximum value, and it keeps constant in phases 3 and 4.

Because of the dependency between Kc and z values and the crop growth phases, the APP offers the user the option to change the average length of the growing cycle. Thus, if the user notes that the growing cycle will be smaller or larger due to climatic conditions,

**Table 1.** Available crops and their p, Kc, and z values, as well as the relative duration of the crop growth phases used by the IrriMobile APP.

| Crop | | Kc | | | Relative phase duration (%) | | | | z (cm) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | p | initial | mid | end | P1 | P2 | P3 | P4 | initial | end |
| Corn (grain) | 0.45 | 1.00 | 1.20 | 0.80 | 17 | 27 | 32 | 24 | 15 | 40 |
| Corn (green) | 0.45 | 1.00 | 1.20 | 1.05 | 22 | 33 | 34 | 11 | 15* | 40 |
| Bean (dry) | 0.45 | 1.00 | 1.15 | 0.65 | 20 | 26 | 34 | 20 | 15 | 40 |
| Bean (green) | 0.45 | 1.00 | 1.15 | 0.90 | 21 | 33 | 33 | 12 | 15 | 40 |
| Soybean | 0.45 | 1.00 | 1.15 | 0.70 | 15 | 19 | 47 | 19 | 15 | 35 |
| Cotton | 0.55 | 1.00 | 1.20 | 0.65 | 17 | 30 | 28 | 25 | 15 | 40 |
| Sorghum (grain) | 0.55 | 1.00 | 1.10 | 0.60 | 16 | 27 | 33 | 24 | 15 | 40 |
| Sorghum (green) | 0.55 | 1.00 | 1.20 | 1.00 | 16 | 27 | 33 | 24 | 15 | 40 |
| Lettuce | 0.30 | 1.00 | 1.05 | 0.95 | 26 | 37 | 26 | 10 | 15 | 25 |
| Carrot | 0.40 | 1.00 | 1.05 | 0.95 | 20 | 30 | 32 | 17 | 15 | 40 |
| Beet | 0.45 | 1.00 | 1.10 | 0.95 | 25 | 35 | 28 | 13 | 15 | 40 |
| Tomato | 0.35 | 1.00 | 1.15 | 0.85 | 20 | 27 | 34 | 19 | 15 | 40 |
| Cucumber | 0.35 | 1.00 | 1.05 | 0.85 | 19 | 28 | 38 | 15 | 15 | 40 |
| Pumpkin | 0.40 | 1.00 | 1.05 | 0.80 | 20 | 30 | 30 | 20 | 15 | 40 |
| Zucchini | 0.40 | 1.00 | 1.05 | 0.80 | 24 | 34 | 26 | 16 | 15 | 40 |

p, soil-water depletion fraction for no stress; Kc, crop coefficient; initial, initial stage; mid, mid-season stage; end, end of the late season stage; P1, P2, P3, and P4, phase 1, phase 2, phase 3 and phase 4; z, effective rooting depth. *The validation of the APP on the green corn cultivation presented in this study was done considering z (initial) equals to 10 cm.

occurrence of pests and diseases, or other factors, the growing cycle length initially registered can be adjusted, improving the performance of the irrigation scheduling.

To record the user activities, the APP has a history system in which information on the soil-water balance, applied irrigation depths, and meteorological data of the management period are saved. This history can be viewed on the smartphone, or exported in CSV format to another device.

IrriMobile was developed using the Java programming language with aid of the integrated development environment Android Studio. Changes such as the addition of new features and changes in the coefficients presented here may be made in future updates (IrriMobile, 2020).

For the validation on a green corn (*Zea mays* L.) crop, the APP was used for irrigation scheduling to evaluate its performance against the methodology proposed by Bernardo et al. (2006), which is widely used in Brazil, with $ET_o$ estimated by the FAO-56 PM equation, hereinafter referred to as Bernardo/FAO-56 PM methodology. In the experiment, the APP was employed with temperature, relative humidity, and rainfall data. After the experiment, the use of the IrriMobile was simulated with only temperature and rainfall data. By comparing the Bernardo/FAO-56 PM methodology and the APP, the overall APP performance was assessed, which depended on the ETo and other variables related to relation between soil, water, plant, atmosphere and irrigation system (Kc, Ks, Kl, z, p, and Ie).

In the experiment, the soil tillage was done in a conventional way; and the manual sowing was performed on September 1st, 2017, with 0.6 m between rows, and 0.2 m between plants. The corn cultivar LG 6033 PRO2 (LG Sementes, Curitiba, PR) was sown. Sprinkler irrigation was applied with overhead sprinklers adjusted to operate in 90º rotation angle, and the fertilization was performed according to Ribeiro et al. (1999). Meteorological data needed for the irrigation scheduling were obtained from a Davis Vantage Pro 2 Plus automatic weather station. Maximum and minimum air temperatures, relative humidity, solar radiation, wind speed at 2 m height, and rainfall were measured daily.

The experiment was composed of two treatments, with irrigation scheduling through the IrriMobile APP (using temperature, relative humidity, and rainfall data) and the Bernardo/FAO-56 PM methodology (using temperature, relative humidity, solar radiation, wind speed, and rainfall data). A completely randomized design with four replicates was carried out. Each plot consisted of eight planting lines of 4 m length, and the four central ones were considered as the useful area; four plants of their extremities were discarded. The irrigation scheduling, with both methodologies, started 25 days after sowing.

The irrigation system was previously evaluated according to Bernardo et al. (2006) by the determination of the irrigation efficiency and application intensity, and the following values were found: 81% and 31.6 mm per hour, respectively. Field capacity (33.7%), permanent wilting point (21.0%) and soil bulk density (1.1 g $cm^{-3}$) were determined in laboratory.

The evaluations described below were performed when plants were at the flowering stage, using 10 plants randomly chosen within the useful area of each plot. Plant height (cm): measurement of the distance from the ground level to the insertion point of the highest leaf, using a measuring tape. Ear insertion height (cm): measurement of the distance from the ground level to the base of the highest ear, using a measuring tape. Stem diameter (mm): diameter of the second internode, measured using a caliper. Total chlorophyll (ICF): two readings with the chlorophyll meter Falker ClorofiLOG on the 9th fully expanded leaf, at points in the middle to two thirds of the length from the base, and 2 cm from one of the leaf margins.

For the following evaluations, 10 ears from different, randomly chosen plants within the useful area of each plot were used. Harvesting was performed when corn reached the milk stage, which occurred on December 12, 2017 (102 days after sowing). Number of bracts per ear: counting of the number of bracts surrounding the ear. Ear length (cm): determined using a ruler. Ear diameter (mm): measurement of the central region of the ear with a caliper. Number of kernels per row: determined as the average number of kernels in four rows of each ear. Number of rows per ear: average number of rows counted in each ear. Cob diameter (mm): obtained by measuring the cob diameter, using a caliper, excluding kernels for a correct exposure of the cob. Kernel length (mm): obtained by subtracting cob radius from ear radius. Number of kernels per ear: determined by multiplying the number of rows by the number of kernels per row. Ear yield determined by weighing 30 fresh ears with bracts from the useful area of each plot (kg per plot). The values obtained were extrapolated to megagrams per hectare. Biomass was obtained by weighing 10 plants cutted at 20 cm from the soil surface in each plot (kg per plot) and, then, extrapolating the values obtained to megagrams per hectare. Water-use efficiency was determined using the Equation 8, as follows:

$$WUE = \frac{YLD}{ET} \quad (8),$$

in which: WUE is the water-use efficiency (kg $m^{-3}$); YLD is the ear yield (kg $ha^{-1}$); ET is the total crop evapotranspiration ($m^3$ $ha^{-1}$) estimated by each methodology, during the evaluation period.

The results were subjected to statistical analysis, by the F test, at 5% probability.

In addition to the aforementioned evaluations, the performance of the APP for estimation of the $ET_o$ was evaluated considering the FAO-56 PM equation as the reference method. To accomplish this procedure, the root mean square error (RMSE), the mean bias error (MBE), and the coefficient of determination ($R^2$) were used, according to Equations 9, 10, and 11, respectively. For comparison purposes, the equations of Hargreaves-Samani (HS) and Penman-Monteith, using only the measured temperatures and relative humidity (PMRH), or only temperatures (PMT) were applied. These equations were used in their original and calibrated forms. The calibrated versions (calibration performed with pooled data from the entirety of Brazil) were obtained in Ferreira et al. (2019). These equations were selected for their good performance in the estimation of $ET_o$ in Brazil (Ferreira et al., 2019). More information on the equations and the calibration process can be seen in Ferreira et al. (2019).

$$RMSE = \sqrt{\frac{1}{n}\sum\left(P_i - O_i\right)^2} \quad (9),$$

$$MBE = \frac{1}{n}\sum\left(P_i - O_i\right) \quad (10),$$

$$R^2 = \left[\frac{\Sigma\left(P_i - \bar{P}\right)\left(O_i - \bar{O}\right)}{\sqrt{\left(\Sigma\left(P_i - \bar{P}\right)^2\right)\left(\Sigma\left(O_i - \bar{O}\right)^2\right)}}\right]^2 \quad (11),$$

in which: $P_i$ is the predicted value (mm $d^{-1}$); $O_i$ is the observed value (mm $d^{-1}$); P is the mean of the predicted values, (mm $d^{-1}$); O is the mean of the observed values (mm $d^{-1}$); and n is the number of data pairs.

## Results and discussion

$ET_o$ and $ET_c$ estimated by the IrriMobile APP generally showed good agreement with those estimated by the Bernardo/FAO-56 PM methodology, mainly when using temperature and relative humidity (Figure 1). The total $ET_o$ and $ET_c$ of the evaluation period obtained by the Bernardo/FAO-56 PM methodology were 260 and 283 mm, respectively. For the APP, when temperature and relative humidity data were used, values were 261 and 290 mm for $ET_o$ and $ET_c$, respectively. When only temperature data were used, values were 288 mm for $ET_o$ and 319 mm for $ET_c$. IrriMobile exhibited better $ET_o$ estimates than the tested equations, with the same meteorological data requirement, showing lower-RMSE and MBE values (Table 2). Even using only temperature, the APP showed a better performance than the PMRH equation (in its original and calibrated forms), which uses temperature and relative humidity. These results corroborate those by Ferreira et al. (2019), who obtained a better performance of the ANNs used in the APP than the evaluated equations.

The soil-water balances performed using the Bernardo/FAO-56 PM methodology and the IrriMobile APP were similar, especially when using temperature and relative humidity data (Figure 2). This behavior indicates that the automatic selection of the coefficients Kc, p, and z was done efficiently. Although p and z values do not directly influence soil-water balance / $ET_c$ estimation, they affect both the TAW calculation, in the case of z, and the irrigation frequency, affecting Ks values which are used to estimate $ET_c$. For the Bernardo/FAO-56 PM methodology, the total irrigation depth applied during the evaluation period was 155 mm. For the APP, 167 (8% higher) and 185 mm (19% higher) were obtained when using temperature and relative humidity data, and when using temperature data only, respectively.

Bernardo/FAO-56 PM methodology and the IrriMobile APP (using temperature and relative humidity data) showed no significant difference between the means (Figure 3), in the evaluations for:

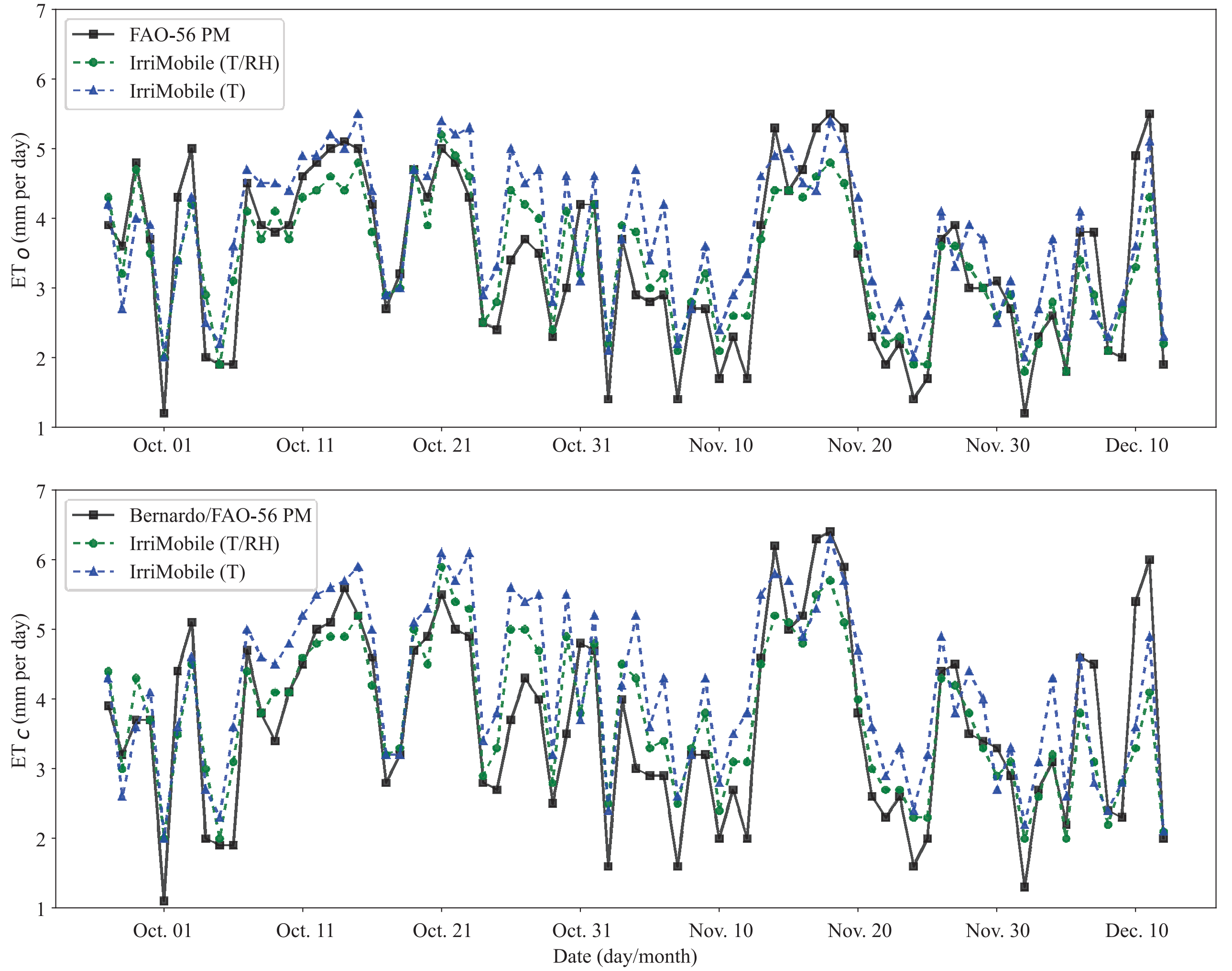


**Figure 1.** Reference evapotranspiration (ETo) and crop evapotranspiration (ETc) values obtained with the Bernardo/FAO-56 PM methodology and the IrriMobile APP.

**Table 2.** Performance of models for estimation of the reference evapotranspiration.

| Model (inputs) | RMSE (mm per day) | MBE (mm per day) | $R^2$ |
|---|---|---|---|
| IrriMobile (T/RH) | 0.55 | 0.01 | 0.82 |
| PMRH (T/RH) | 0.86 | 0.67 | 0.82 |
| PMRH cal (T/RH) | 0.81 | 0.60 | 0.82 |
| IrriMobile (T) | 0.75 | 0.36 | 0.70 |
| HS (T) | 1.59 | 1.46 | 0.74 |
| HS cal (T) | 1.09 | 0.89 | 0.74 |
| PMT (T) | 1.23 | 1.06 | 0.74 |
| PMT cal (T) | 1.05 | 0.85 | 0.74 |

T, air temperature; RH, relative humidity; cal, calibrated version of a model.

plant height (PH); ear insertion height (EIH); stem diameter (SD); total chlorophyll (TC); number of bracts per ear (NBE); ear length (EL); ear diameter (ED); number of kernels per row (NKR); number of rows per ear (NRE); cob diameter (CD); kernel length (KL); number of kernels per ear (NKE); ear yield (EY); biomass (BIO); and water-use efficiency (WUE).

Regarding the corn vegetative parts (PH, EIH, SD, and TC), the mean values obtained for PH and EIH were higher than those obtained by Demétrio et al. (2008), who obtained 2.35 and 0.96 m, respectively, and by Farinelli & Lemos (2010), who obtained mean values of 2.51 and 1.58 m, respectively. The SD also exceeded the values obtained by Demétrio et al. (2008), and it was within the range of values reported by Farinelli & Lemos (2010).

Given that TC was measured with the Falker ClorofiLOG chlorophyll meter, which uses the FCI scale (Falker chlorophyll index), no studies were found using this device on corn crop. Thus, since Falker ClorofiLOG and SPAD use the same measurement scale (Barbieri Junior et al., 2012), comparisons were made using the SPAD scale. According to Argenta et al. (2001), SPAD values of 55.3 and 58.0, in the stages of 10–11 fully expanded leaves and kernel development, respectively, represent adequate levels of foliar nitrogen. Therefore, the value obtained in the present study – 61 FCI for both studied methodologies –, can be considered satisfactory.

For the variables related to ear (NBE, EL, ED, NKR, NRE, CD, KL, and NKE), the values obtained were mostly equal to or higher than those reported by Souza et al. (2016a). To be within market standards, ears of sweet corn should have minimum EL and ED of 15 cm and 30 mm, respectively (Albuquerque et al., 2008). In the present work, ears evaluated were within this standard since they showed mean EL and ED equal to 19.4 cm and 47.8 mm, respectively.

For EY, high values were observed, with 26.6 Mg ha$^{-1}$ mean value. This value exceeds those reported by Luz et al. (2014), who obtained means ranging from 14.32 to 24.38 Mg ha$^{-1}$. High-ear and grain yields generate benefits for both farmer and industry (Luz et al., 2014). High-BIO production was also obtained, with of 90.4 Mg ha$^{-1}$ mean value. This result can be attributed to the high vegetative vigor observed and the relatively high-plant population used (83,333 plants ha$^{-1}$).

The WUE obtained (9.29 kg m$^{-3}$) was higher than the highest value (7.04 kg m$^{-3}$) obtained by Souza et al. (2016b); this result probably occurred due to the high-ear yield and to the relatively low evapotranspiration during the corn growing cycle, in addition to the fact

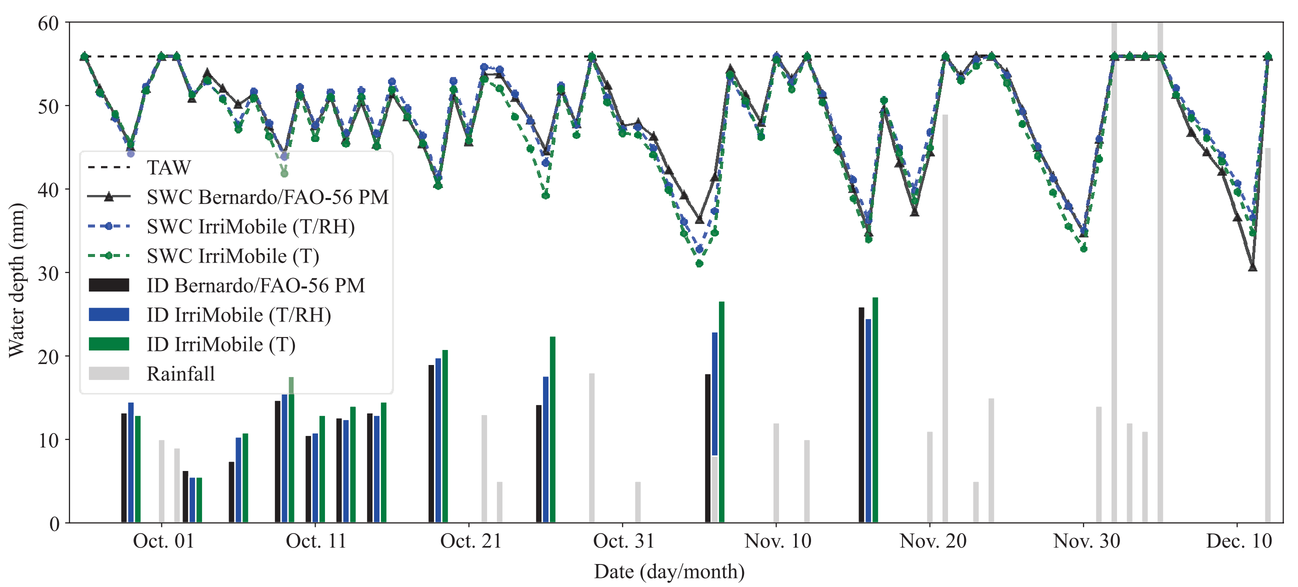


**Figure 2.** Soil-water balance during the experiment using the IrriMobile APP and the Bernardo/FAO-56 PM methodology. TAW, total available water; SWC, soil-water content; ID, irrigation depth.

that the irrigation scheduling ($ET_c$ accounting period) started 25 days after sowing.

Although the APP exhibited a slightly higher-water consumption during the experiment (using temperature and relative humidity), which was 8% higher than that observed for the Bernardo/FAO-56 PM methodology, the results obtained represent an excellent performance for a simplified method. In the simulation using only temperature, water consumption was 19% higher than that recommended by the Bernardo/FAO-56 PM methodology. However, in practical situations, the applied irrigation depths can be much higher than those required by the crops. Thus, the IrriMobile APP represents a low-cost and promising alternative

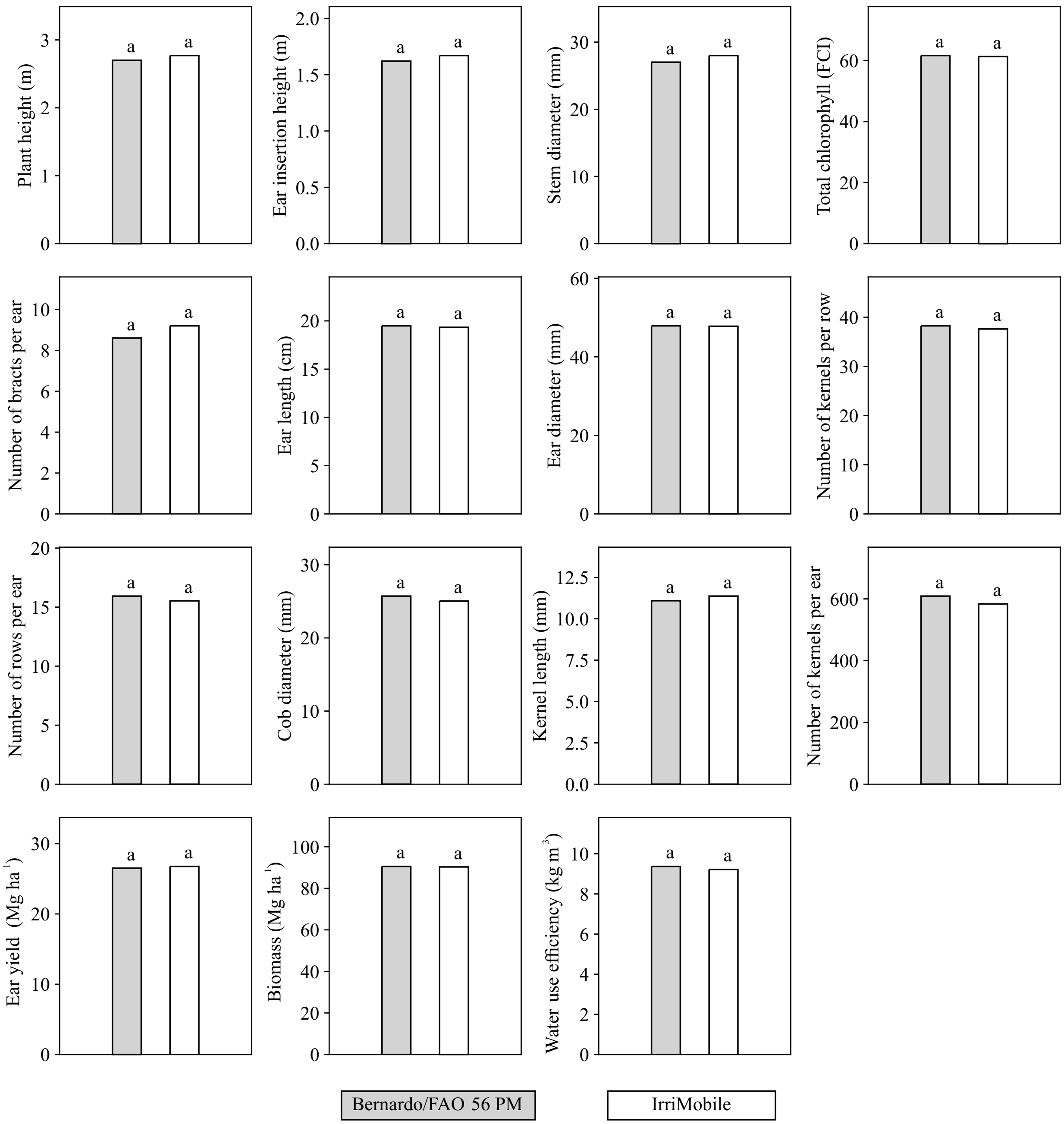


**Figure 3.** Mean values of analyzed variables obtained using the Bernardo/FAO-56 PM methodology and the IrriMobile APP. Means followed by equal letters, do not differ by the F-test, at 5% probability.

for irrigation scheduling, especially when using temperature and relative humidity data. Future studies can be conducted by evaluating the APP for other locations and crops.

## Conclusion

The IrriMobile APP is efficient for the irrigation scheduling on green corn crop, using only air temperature and relative humidity data, besides information on rainfall.

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