Development and testing of an irrigation scheduling model

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Accepted 11 January 2000

Abstract

An irrigation scheduling model (ISM) consisting of a database management system (DBMS), model base and graphical user interface (GUI) was developed for performing irrigation scheduling under various management options for both single and multiple fields. The ISM is based on a daily water balance approach and uses climatological, crop and soil data as input. Depending on the availability of climatological data, the model offers a choice of one or more methods of estimating reference evapotranspiration (ETo). The GUI is based on mouse-driven approach with pop-up windows, pull-down menus and button controls. The model was tested against field data and the CROPWAT model. The model-predicted soil moisture contents were compared with the field-measured data for both single and multiple field cases. The two models, ISM and CROPWAT, gave similar values of soil moisture but showed some variation after the second irrigation. For both the single- and multiple-field cases, simulated bean yield was slightly higher than measured yield. Also, except for the Turc method, all ETo estimation methods resulted in higher yield as compared to measured yield. The ISM is a flexible and user-friendly irrigation-scheduling tool, which can be used for efficient use of irrigation water. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Modeling; Irrigation scheduling; Soil water balance

1. Introduction

Over the past decade, many countries around the world have witnessed a growing scarcity of and competition for water among different users (domestic, municipal,
industrial, and environmental purposes). Therefore the increasing water demands can be met either through the development of new water resources or by using the existing resources more efficiently. In India, the development of new water resources is not economically viable and faces strict environmental resistance. The majority of irrigation projects in the country perform at a low overall efficiency of 30% (Sarma and Rao, 1997). This low overall efficiency provides an opportunity for meeting the increasing water demands by improving performance of the existing irrigation projects. This approach requires less investment as compared to the development of new water resources. The intensive irrigation practices without proper water management strategies are causing over-exploitation of groundwater and thus decline of water table in some areas, whereas other areas are witnessing salinity and water logging problems. In agricultural water management, significant improvements can be achieved through irrigation scheduling.

Irrigation scheduling deals with two questions, when and how much to irrigate a crop. Quantitative irrigation scheduling methods are based on three approaches, namely, crop monitoring, soil monitoring and water balance technique. For the methods based on crop monitoring, leaf water potential (Stegman et al., 1976; Turner, 1988) or canopy temperature (Jackson et al., 1977; Wanjura et al., 1995) is measured at several places in the field to decide when to irrigate. The major drawback of this method is that the decision to irrigate is made after the plant has suffered some amount of moisture stress, which may adversely affect the crop yield. Soil moisture monitoring can be effectively used for irrigation scheduling purpose. However, this process is labor-intensive and time consuming and thus it may not be economical.

Soil water balance based irrigation scheduling models use soil water budgeting over the root zone. A number of computerized simulation models (Feddes et al., 1974; Kincaid and Heermann, 1974; Rowse et al., 1983; Camp et al., 1988; Smith, 1991; Foroud et al., 1992) for crop water requirements have been developed using this approach. These models have been widely accepted and used by irrigation researchers and other professionals, but their adoption by farmers has been very slow. The slow acceptance of irrigation scheduling models may be attributed to two reasons. The first is that the models written for large computers were not readily accessible to growers or were not user friendly. Secondly, the lack of suitable potential evapotranspiration (ET0) expressions also limits the adoption of such techniques. Furthermore, many models can only be used for irrigation scheduling for a single field, and their application for multiple fields requires running the model for each field separately. Thus, there is a need to develop a user-friendly irrigation-scheduling model that can be readily used by farmers for single and multiple field cases.

The objective of the present work is to develop an irrigation scheduling models (ISM) consisting of a database management system for storing and retrieval of data along with a user-friendly graphical interface. Furthermore, the model should include options for choosing different root growth functions, crop stress function, effective rainfall, ET0 estimation method and irrigation scheduling criteria (fixed depth, fixed interval, variable depth and variable interval). The developed model was tested against the field data and also with the CROPWAT model (Smith, 1991). The model description and results are presented herein.
2. Irrigation scheduling model

The ISM was developed to schedule the irrigation for different crops grown in different fields. The model has two components, soil water balance (irrigation scheduling) and crop yield. The ISM is based on conservation of mass approach. A detailed description of soil water balance model is given below.

2.1. Soil water balance sub-model

ISM require an understanding of the soil water balance for estimating the amount of water in the crop root zone at a given time. The soil water balance can be expressed in terms of soil moisture depletion as

\[ \text{SMD}_{ij} = \text{SMD}_{i-1,j} + \text{ET}_{ij} + \text{DP}_{ij} - I_{ij} - R_{ij} \]  

(1)

where SMD = total soil moisture depletion in the root zone and is defined as the difference between total soil moisture stored in the root zone at field capacity and the current moisture status in cm; ET = evapotranspiration in cm; DP = deep percolation in cm; \(I\) = net irrigation amount in cm; \(R\) = effective rainfall in cm; \(i\) = time index; and \(j\) = space index (fields).

Daily evapotranspiration can be calculated using the following relationship (Jensen and Heermann, 1970)

\[ \text{ET}_{ij} = \text{ETo}_{ij} \left[ K_{ci,j} K_{kij} + K_w (0.9 - K_{ci,j}) \right] \]  

(2)

where ETo = grass reference crop ET in cm; \(K_c\) = dimensionless crop coefficient which is a function of the crop type and the growth stage; \(K_s\) = dimensionless crop stress coefficient which is a function of the soil moisture available to the crop; \(K_w\) = dimensionless ET correction coefficient, which is 0.8, 0.5 and 0.3 respectively, for the first, second, and third day following a rainfall or irrigation event to account for excessive evaporation from the bare soil surface in the beginning of the cropping season. The second term is set equal to zero for \(K_c > 0.9\) and also for a period greater than 3 days after an irrigation or rainfall event. Field scale spatial variability in climatic conditions is assumed constant for any day during the growing season. The climatic conditions do change in time, however, causing temporal variability in ETo.

ETo is a function of climatic conditions and can be estimated using different methods depending on the availability of climatic data. Nine most commonly used and internationally accepted ETo estimation methods based on combination theory, solar radiation, temperature, and pan evaporation were included in the present model. These are Penman–Monteith (Allen et al., 1994), FAO-24 Penman (Doorenbos and Pruitt, 1977), 1982 Kimberly–Penman (Wright, 1982), FAO-24 Radiation (Doorenbos and Pruitt, 1977), Priestley–Taylor (Priestley and Taylor, 1972), Turc (Turc, 1961), Hargreaves (Hargreaves and Samani, 1985), FAO-24 Blaney-Criddle (Doorenbos and Pruitt, 1977) and Christiansen Pan Evaporation (Christiansen, 1968). The model allows the selection of any one or more ETo estimation methods from the above nine available.

The effect of water stress on ET is usually provided by the crop stress factor, which is based on the soil water content. The crop stress factor \((K_s)\) can be estimated using either a
linear function (Hanks, 1974; Ritchie, 1973) or a logarithmic function (Jensen et al., 1971). The linear function is given as

\[ K_{s,ij} = \frac{(\theta_{c,j} - \theta_{pwp,j})}{\theta_{c,j}} \cdot RD_{ij} \quad \text{when} \quad \theta_{c,j} > \theta_{j} > \theta_{pwp,j} \]

(3)

\[ K_{s,ij} = 1.0 \quad \text{when} \quad \theta_{c,j} < \theta_{j} \]

(4)

where \( \theta_{c} \) = critical soil moisture content, \( \theta_{pwp} \) = volumetric soil moisture content at permanent wilting point, \( \theta_{j} \) = volumetric soil moisture content on day \( i \); and \( RD \) = root depth in cm.

The logarithmic function is given as

\[ K_{s,ij} = \frac{\log[1 + 100(1 - (SMD_{i-1,j}/AWC_{ij})]}}{\log[101]} \]

(5)

where \( AWC \) = total available soil moisture storage capacity in cm and is defined as the difference between moisture contents at field capacity and permanent wilting point. \( K_{s} \) vary spatially with variability of soil properties (field capacity and permanent wilting point), soil moisture depletion at the beginning of the season or following an irrigation event, and finally at root development.

The amount of water that can be used by a crop depends on the water holding characteristics of the soil and on the rooting depth of crop. The maximum effective root depth depends on several environmental, crop and soil factors. Temporal root depth can be calculated by using either the sigmoidal (Borg and Grimes, 1986) or linear growth function (Kincaid and Heermann, 1974).

Deep percolation from the root zone occurs when excess water from rain or irrigation fills the root zone beyond field capacity. Deep percolation can be computed by the method proposed by Ritchie (1985). Effective rainfall is that part of the rain which infiltrates into the soil and is available for crop use. Effective rainfall is difficult to estimate because of the changes in infiltration rate with time and soil conditions, and because of spatial and temporal variability of rain. Effective rain can be calculated by using either the fixed-percentage of rainfall or USDA, Soil Conservation Service (1967).

After integrating all components of soil water balance model, the soil-water status in the root zone can be simulated to predict the date and amount of irrigation according to user-defined options on root growth, crop stress factor, effective rainfall and irrigation schedules. The available options for root growth, crop stress factor and effective rainfall were discussed earlier. The irrigation scheduling options include fixed interval, fixed depth, and MAD (management allowable depletion), which include variable interval and variable depth. The water balance equation can be solved for any one of the three conditions. For irrigation schedules based on fixed interval, fixed depth and MAD criteria, the user has to specify the desired interval between two consecutive irrigation event, irrigation depth and MAD level, respectively.

For fixed interval, the estimated irrigation requirement is equal to soil moisture depletion at the end of the interval, whereas for fixed depth case, irrigation is required
when soil moisture depletion becomes equal to irrigation depth. In the case of irrigation scheduling based on MAD, both day of irrigation and depth are estimated as follows:

$$AD_{ij} = AWC_{ij} \times P_j$$  \hspace{1cm} (6)

where $AD$=allowable depletion in cm, $P$=management allowable depletion limit, defined as the fraction of $AWC$ that can be safely removed from the soil to meet the daily ET demand on day $i$. In this case irrigation is given on the day $i$, when the soil moisture depletion reaches the allowable depletion. The required irrigation depth is equal to soil moisture depletion. In each case, the model predicts irrigation schedules and allows the user to specify the depth of irrigation to be applied. However, the default value for applied depth is equal to the model predicted depth.

2.2. Crop yield sub model

The yield of a crop is determined by many factors that contribute to plant performance. Water is a critical factor because, both independently and interactively with other factors, water availability affects crop biological functions and growth. Crop yield can be predicted from simulated seasonal ET using an ET-yield relationship (yield function). The relative yield function suggested by Martin et al. (1984) was used to predict crop yield.

$$\frac{Y}{Y_m} = (1 - b_c) + b_c \left( \frac{ET_s}{ET_m} \right)$$  \hspace{1cm} (7)

Where $Y$=actual crop yield in t/ha; $Y_m$=maximum attainable crop yield in t/ha; $b_c$=ET-Yield coefficient; $ET_s$=seasonal evapotranspiration in cm; and $ET_m$=maximum seasonal ET needed for maximum yield in cm.

ISM was developed using MS Developer Studio Version 5.0 Visual Basic. It can be run on any Pentium based PC, running at 150 MHz or higher with 32MB RAM under Win 95/Win NT environment.

2.2.1. Graphical user interface and database management system

The graphical user interface (GUI) is the most important feature of the program as it provides a better interaction between the model and user. It is based on a mouse-driven approach with pop-up windows, pull-down menus and button controls. The main window of the interface consists of eight pull down menus including File, Edit, Data form, Data input, Options, Results, View and Help (Fig. 1). These menus have sub menus and sub-sub menus.

Climatic data can be input through form containing various fields (eg. date, maximum and minimum temperature, maximum and minimum relative humidity, wind speed, ratio of day and night wind speed, solar radiation, sunshine hours, pan evaporation and rainfall) along with an option for Climatic Station name and can be accessed by clicking ‘Data Form’ in main menu and then on ‘Climatic Data’. The data provided by the user through Input Climatic Data dialog box is directly added to MS Access database.

Input Crop Data dialog box can be open by clicking ‘Data Input’ menu bar and then on ‘Crop Data’ (Fig. 1). The user can either enter new crop data or retrieve earlier saved
data. The user can input soil data in a similar way by opening the Input Soil Data dialog box by clicking ‘Data Input’ menu bar and then on ‘Soil Data’.

The Scheduling Options dialog box can be accessed by clicking on ‘Options’ in the menu bar. The user has to provide options for root growth, crop stress factor and effective rainfall and criteria for irrigation scheduling. These options are categorized and grouped. Accordingly the user can check only one option at a time in the group. For a given crop, soil and climatic conditions the user can either create input data files using forms or retrieve the earlier created files. For performing multiple fields irrigation scheduling, information on soil, crop, climate and option need to be specified for each field.

The model provides output related to irrigation schedules and daily soil water balance. Irrigation scheduling output (Fig. 2) includes crop name, climatic station, planting date, harvesting date and predicted yield besides irrigation number, date of irrigation, required depth (cm), applied depth (cm) and deficit (cm). The required depth is the depth calculated by the program according to irrigation scheduling options checked by the user and the applied depth is the depth provided by the user during each irrigation event. The soil water balance provides information on daily values of crop coefficient (fraction), crop stress factor (fraction), actual ET (cm), rooting depth (cm), deep percolation (cm), effective rainfall (cm), irrigation amount (cm) and soil moisture depletion (cm) besides the crop name, climatic station, planting date, harvesting date and length of cropping season.
3. Input data and methodology

For testing the model, field data related to Yolano Pink bean crop were taken from experiments conducted at the University of California, Davis, during the summer of 1992 (Raghuvanshi, 1994). The plot was approximately 265 m long and 16 m wide. On 10 June, 20 rows of Yolano Pink beans were planted on 35 cm wide beds in rows spaced 80 cm apart. The day after planting, aluminum access tubes were installed to a depth of 1.8 m at 10 m intervals in the middle of the bed of the ninth row from the west edge of the experimental plot. A furrow adjacent to the bed (East Side) with the aluminum access tube was selected as a test furrow. Irrigation was applied prior to planting on 1 June to fill the root zone and enhance germination. During the growing season (10 June–8 September), three irrigations were applied at a fixed interval of 21 days (1, 22 July and 12 August). There was no water table present in the vicinity of the root zone.

Soil moisture was monitored by a Campbell Pacific Nuclear Probe model 503-DR. During the experiment, soil moisture readings were taken between 7:15 a.m. and 9:45 a.m., and tubes were read in a systematic pattern, i.e., measurements were started at the upstream-end tube (0 m) and ended at downstream-end tube. Probe readings at depths of 15, 30, 60, 90, 120, and 150 cm represent average soil moisture contents for depth intervals from 0 to 22.5, 22.5 to 45, 45 to 75, 75 to 105, 105 to 135, and 135 to 165 cm,
respectively. At the end of the growing season, bean yield for a 2 m transect, centered on the access tube, was measured at all 27 tube locations.

Field capacity (FC) and permanent wilting point (PWP) moisture contents at 10 m intervals were taken from data presented by Raghuwanshi (1994). The FC of the study area varies from 29.88 to 33.41% and PWP varies from 11.42 to 17.62%. Average soil moisture contents at FC and PWP were 32.5 and 15%, respectively. The hydraulic conductivity of the soil was 0.01 cm/day (La Rue et al., 1968). The minimum and maximum rooting depth depths were 15 cm (equal to depth of sowing) and 85 cm, respectively. The values of the ET-Yield coefficient, maximum attainable bean yield and maximum ET were 1.27, 4.12 t/ha and 41.6 cm, respectively, and were obtained from the results of an earlier field experiment on the same crop and soil (Tosso, 1978). Information on length of different bean growth stages and their corresponding crop coefficients is given in Fig. 1.

California Irrigation Management Information System (CIMIS) collects meteorological data (hourly and daily) from weather stations located in different regions of the state and calculates grass reference crop ET. The nearest weather station (Davis) was 200 m west of the field site. Therefore, CIMIS estimates of grass reference crop ET for the growing season (10 June–8 September) were used as ETo.

For testing the performance of the model, linear root growth function, logarithmic crop stress function, fixed percentage (80%) effective rainfall and 21 days fixed interval irrigation scheduling options were considered. For single and multiple field cases, the ISM was used to simulate daily water balance for complete bean crop growing season using the input data and options described above. Average value of FC, PWP and applied irrigation depth were used in the single field case, whereas different values of FC, PWP and measured irrigation depths were used in the multiple field case. Each location along the furrow was assumed to represent a separate field, since FC, PWP and applied irrigation depths were different. The model gave daily soil moisture depletion values, which were utilized for estimating daily root zone available soil moisture. The neutron probe measurements at depths of 15, 30, 60 and 90 cm were used to determine the profile average soil moisture storage, since they represented the root zone. Daily simulated soil moisture storage values were compared with the daily profile average soil moisture storage for each location and daily field average soil water storage values (average of daily soil water storage of 27 locations), respectively, in the multiple-fields and single-field cases. Furthermore, for the single-field case, model-predicted soil moisture was compared with CROPWAT-predicted soil moisture. Yield predicted using different ETo estimation methods was compared with measured yield for the single-field case. The results are presented in the following section.

4. Results and discussion

4.1. Single field case

Field average applied and predicted irrigation depths for the first, second and third irrigations were 3.92, 4.14 and 10.43 cm and 2.13, 9.13 and 13.50 cm, respectively. The
applied depth was more than the predicted for the first irrigation but it was less for the second and third irrigation.

A comparison of measured and simulated soil moistures is shown in Fig. 3. In the beginning of the season, the measured soil moisture was less than the simulated soil moisture but this trend reversed later in the season. The difference in measured and simulated water contents might have been caused by changes in neutron probe calibration curve during the season. The accuracy of a neutron meter in estimating soil water content and depletion is usually affected by many factors including length of count interval, probe calibration and spatial heterogeneity of soil water (Farah et al., 1984). Also, various soil properties other than soil moisture produce a cumulative effect on the count rate and probe calibration. The relationship between neutron count rate and soil water content does not seem to be unique (Hodgson and Chan, 1987), as variation occurs with seasonal changes in organic matter, bulk density, the presence of neutron absorbers such as boron, cadmium and chlorine, and the bound water content of the soil. However, in this study a single calibration curve was used for all depths throughout the season.

4.2. Multiple field case

Applied and predicted irrigation depths at all 27 locations for three irrigation events are given in Fig. 4. During the first irrigation, all the locations received more water than required, but the applied irrigation depths were less than required for the last two irrigations. The excess water during the first irrigation resulted in deep percolation, since there was no runoff from the field. However, there was no deep percolation during the second and third irrigation events because the applied depths were less than model-predicted depths.

Soil moisture content was simulated for all the 27 locations along the furrow. Figs. 5 and 6 show the comparison between simulated and measured soil moisture contents at the
beginning of the furrow (0 m) and at 130 m from the upstream end of furrow, respectively. Measured soil moisture was higher than simulated moisture after the first irrigation at 0 m. At this location, higher soil moisture might have resulted due to less soil moisture depletion since there was no crop on the upstream end of access tube. Comparison between simulated and measured soil moisture values at 130 m showed close agreement (Fig. 6). However, the measured moisture content change due to the third irrigation was less than the predicted change. This could have been caused by an error in measurement of applied depth since there were cracks in the field. The Mean Absolute
Relative Error (MARE) criterion was used, further, to investigate the model’s predictive performance and is given below

$$MARE = \frac{\sum_{i=1}^{n} (|Simulated_i - Observed_i|/Observed_i)}{n}$$

Equation (8)

For all 27 locations, MARE values were estimated considering entire cropping season and are shown in Fig. 7. The maximum and minimum MARE values were 15 and 4% respectively, which correspond to 0 and 130 m. MARE values were less than 10% except for a few locations at the upstream end. At these locations, high MARE values might have resulted from errors in measured depths or changes in calibration curve.

![Figure 6. Simulated and observed soil moisture content at 130 m from the upstream end of the furrow.](image)

![Figure 7. Mean absolute relative error at different locations in the field.](image)
4.3. Comparison between ISM and CROPWAT

Using the same data over the growing season, daily soil moisture values predicted by the ISM and CROPWAT are shown in Fig. 8. The two models gave similar values of soil moisture and showed some variation after the second irrigation. This minor variation might be caused by inaccurate rooting functions, ET estimations or other differences in the two models.

The distribution of soil moisture values around 1:1 line is shown in Fig. 9. The soil moisture values predicted by ISM were slightly higher than those predicted by the CROPWAT. Most of the values predicted by the ISM lie between the 1:1 line and the CROPWAT predicted soil moisture +5% CROPWAT line and all the values are found to
be below the CROPWAT predicted soil moisture +15% CROPWAT line. Regression analysis of soil moisture simulated by the ISM and CROPWAT resulted in a high $r^2$ value (0.98). Therefore, it can be concluded that the model’s performance was similar to the CROPWAT model. However, the ISM has a lot of advantages over the CROPWAT. The ISM considers daily variations in climatic data for predicting the soil moisture depletions whereas the CROPWAT uses average monthly ET value which may result in under or over-prediction of irrigation depth if there is a large variation in daily climatic conditions. Furthermore, the ISM provides flexibility in selecting ETo estimation method based on climatic data availability. The model also has the ability to schedule irrigation according to the availability of water. This can be done by the ‘Smart Schedule’ module in the model. After each irrigation turn, the smart schedule input box appears on the screen that allows the user to specify the irrigation depth based on water availability. However, the present version of the ISM does not have the ability to graphically represent the output.

4.4. Comparison of bean yield

For the single field case, the model predicted bean yield was 7% greater than that measured in the field. Yields measured at 27 locations were compared with the predicted yields for the multiple field case (Fig. 10). The predicted and measured yields and variation were similar for all locations. Yields declined with increasing distance from the origin, except that measured yield increased at the down stream end of the furrow. Higher measured bean yield at the down stream end might have been caused by water ponding near the down stream end, which is not considered by the model.

Recall that in the above studies CIMIS estimates of ETo were used. Considering a single field case and different ETo computation methods (Hargreaves, 1982 Kimberly–Penman, FAO-24 Penman, Penman–Monteith, Priestly–Tailor, FAO-24 Radiation and Turc) bean yield was predicted and compared with the field-measured yield (Table 1).
Except for the Turc method, all methods resulted in higher yield because of higher ETo estimates relative to CIMIS ETo. The Penman–Monteith, Priestly–Taylor, FAO-24 Radiation methods resulted in the same yield values, and the 1982 Kimberly–Penman and FAO-24 Penman performed similarly.

5. Summary and conclusions

The ISM, consisting of a database management system (DBMS), model base and GUI was developed to schedule irrigation for different crops grown in a command area. The model is very user friendly and easy to operate due to the window interface. The user can give the options to calculate the root depth, crop stress factor and effective rainfall. Further, the model provides flexibility in choosing irrigation scheduling criteria (fixed depth, fixed interval and management allowable depletion) and ETo estimation method depending on availability of climatic data.

The ISM is based on the soil water balance method and requires climatic, crop and soil data as inputs. The model offers detailed output related to irrigation schedules and daily soil water balance. The model was tested for field data related to bean crop, taken from experiments conducted at University of California, Davis and was also compared with the CROPWAT model. Measured soil water contents were compared with simulated water contents for both single field and multiple field cases.

For the single field case, measured soil moisture was less than simulated soil moisture at the beginning of the season but this trend reversed later in the season. For the multiple field case, measured soil moisture was higher than simulated moisture at the up stream end of the furrow (0 m) after the first irrigation. Simulated and measured soil moisture values were similar at the 130 m furrow position. Mean absolute relative error in soil moisture varied from 4 to 15%. Soil moisture predicted by the ISM was slightly higher than that predicted by the CROPWAT, but regression analysis resulted in a high $r^2$ value (0.98). For both single and multiple field cases, simulated bean yields were slightly higher than the field measured yields. Except for the Turc method, all ETo estimation methods resulted in slightly higher predicted yields than measured yields.

<table>
<thead>
<tr>
<th>ETo method</th>
<th>Yield (t/ha)</th>
<th>Deviation in yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hargreaves</td>
<td>3.13</td>
<td>9</td>
</tr>
<tr>
<td>1982 Kimberley–Penman</td>
<td>3.37</td>
<td>17</td>
</tr>
<tr>
<td>FAO-24 Penman</td>
<td>3.31</td>
<td>15</td>
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<tr>
<td>Penman–Monteith</td>
<td>3.19</td>
<td>11</td>
</tr>
<tr>
<td>Priestley–Taylor</td>
<td>3.19</td>
<td>11</td>
</tr>
<tr>
<td>FAO-24 Radiation</td>
<td>3.21</td>
<td>11</td>
</tr>
<tr>
<td>Turc</td>
<td>2.73</td>
<td>−5</td>
</tr>
<tr>
<td>CIMIS</td>
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<td>7</td>
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<tr>
<td>Field measured</td>
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Table 1
Yield values for different ETo calculation methods
Based on these results, the ISM is found to be a flexible and user-friendly tool for predicting the status of soil moisture contents throughout the crop-growing period. It can assist its users in making day-to-day decisions for the efficient use of irrigation water.

References


