EXECUTIVE SUMMARY

Introduction

In large areas of South Africa, irrigation is required in order to achieve optimal yields. Crop water requirements need to be accurately quantified to improve the efficiency of irrigation water management.

The best estimates of crop water use result from direct measurements, but this is not always feasible on a large scale. The next most accurate approach would be one which integrates our understanding of the soil-plant-atmosphere continuum as mechanistically as possible. Taking the supply of water from the soil-root system, and the demand from the canopy-atmosphere system into account is essential to properly describe crop water use. The Penman-Monteith reference crop evaporation (Smith, Allen and Pereira, 1996) together with a mechanistic crop growth model, which uses soil water and grows a realistic canopy and root system provides the best possible estimate of the soil water balance. This approach has been out of reach of irrigators due to the specialist knowledge required to run the models. This high management cost can be drastically reduced by packaging the model in an extremely user-friendly format, eliminating the need for a detailed understanding of the intricacies of the soil-plant-atmosphere continuum. The benefits will be increased too, because of the accuracy of the mechanistic, and therefore universally valid, estimation procedure.

The interest in scheduling irrigations with crop growth computer models is rapidly increasing particularly since personal computers have become accessible to crop producers. Most of the existing models, however, either are crop specific or do not simulate daily crop water use. Some models are relatively simple to use for planning purposes, but do not allow real-time scheduling. Other models accurately describe the complexity of natural processes. This makes them suitable for research purposes, but they are generally not applicable in practice due to the large amount of input data required and lack of a user-friendly interface.

The Soil Water Balance (SWB) model is a mechanistic, real-time, generic crop, soil water balance, irrigation scheduling model. It is based on the improved generic crop version of the NEW Soil Water Balance (NEWSWB) model (Campbell and Diaz, 1988). SWB gives a detailed description of the soil-plant-atmosphere continuum, making use of weather, soil and crop management data. It thus largely overcomes the problems of other models for irrigation scheduling as indicated above. However, since SWB is a generic crop growth model, parameters specific for each crop have to be determined.

Aims

In order to make the SWB model more generally applicable and accessible, the following objectives were identified for this project:

i) To determine parameters for specific crops which are commonly irrigated in South Africa, and include them in the SWB database;
ii) To identify further development needs in respect of SWB in order to meet user requirements;
iii) To automate the acquisition of input weather data from automatic weather stations in order to facilitate and make scheduling more convenient;
iv) To evaluate SWB using independent data sets obtained from South African researchers and organizations;
v) To develop a user-friendly Windows 95 interface for easy technology transfer;
vi) To compile a comprehensive user manual;
vii) To compile a comprehensive user help facility; and
viii) To identify further research and model development needs which are not satisfied in this project.

Approach

Calibration and validation of SWB with independent data sets of relevance for irrigation scheduling was required in order to establish the reliability of the model in representing the real-world system. Three approaches were followed in order to meet these requirements:

i) An extensive literature search of Water Research Commission publications and others was carried out. Personal contacts with South African researchers and organizations were also made in order to obtain data sets.

ii) In the absence of useful data sets for some crops, field trials were carried out in order to collect data for the determination of specific crop growth parameters.

iii) An alternative model for estimating the soil water balance was developed for crops for which data sets were not available in the literature or through personal contacts, and where it was not possible to set up field trials to determine specific crop growth parameters. This model is based on the crop factor approach recommended by the FAO (Food and Agricultural Organization of the United Nations, Rome, Italy). It was developed in order to include more crops in the SWB crop database, by making use of the database of crop factors available in FAO publications.

Data sets for the validation of SWB were therefore sought for two types of model:

i) Crop growth and soil water balance model making use of specific crop growth parameters; and

ii) FAO-based model making use of FAO crop factors.

Methodology

Severe difficulties were encountered in the attempt to obtain complete, reliable and useable data sets for the validation of SWB. In most cases, available data sets were incomplete, in others potential collaborators were reluctant to make data available.

The following South African researchers are gratefully acknowledged for making complete independent data sets available for the calibration and validation of SWB:

i) Dr M Hensley (Institute for Soil, Climate and Water - Agricultural Research Council, Glen):

   - Dry land maize grown at Setlagole, Ermelo and Kroonstad.

ii) Prof S Walker (University of the Orange Free State, Bloemfontein) and Dr TP Fyfield (Institute for Soil, Climate and Water - Agricultural Research Council, Pretoria):

   - Irrigated wheat grown at Roodeplaat.

iii) Prof ATP Bennie (University of the Orange Free State, Bloemfontein):

   - Irrigated maize, peanuts, peas, potato and wheat grown at Bloemfontein.
   - Irrigated and dry land soybean grown at Castana (Iowa, USA).

iv) Dr MG Inman-Bamber (formerly South African Sugar Association Experiment Station, Mount Edgecombe; presently CSIRO, Townsville, Australia):

   - Sugarcane grown at Pongola.

v) Ms T Volschenk (Agricultural Research Council - Infruitec, Stellenbosch):

   - Apples grown at Elgin.

vi) Mr A Nel (Grain Crops Research Institute - Agricultural Research Council, Potchefstroom):

   - Sunflower grown at Potchefstroom.

vii) Dr GC Green and Mr HM du Plessis (Water Research Commission):

   - Citrus.

In the absence of useful data sets for vegetables, a field trial was set up at Roodeplaat in cooperation with Mr W van Wyk (Department of Agriculture - Directorate of Plant and Quality

Control, Pretoria). The objective was to determine specific crop growth parameters for several irrigated vegetable species, and include them in the database of SWB.

In the absence of time consuming and therefore expensive growth analysis data, a simpler modelling approach was required. An FAO-based crop factor procedure has therefore been developed and combined with the mechanistic SWB model, thereby still allowing evaporation and transpiration to be modelled separately as supply- and demand-limited processes. The crop factor model does not grow the canopy mechanistically and therefore the effect of water stress on canopy size is not simulated. The simpler crop factor model should, however, still perform satisfactorily if the estimated canopy cover closely resembles that found in the field.

The FAO model was mainly developed in order to include more crops in the SWB crop database, by making use of the database of basal crop coefficients, growth periods, root depths, crop heights, stress factors and potential yields available in FAO publications (Doorenbos and Pruitt, 1992; Smith, 1992a; Allen, Smith, Pruitt and Pereira, 1996). In particular, tree crops were critical as growth analyses for trees are seldom available.

A field trial was carried out at Hatfield in order to determine FAO crop parameters for peach trees. Specific crop growth parameters for peaches were not determined as it was not possible to carry out growth analysis due to the limited number of trees and limited time available.

Results

Data obtained from the field trials were used to calibrate SWB.

Weather, soil and growth analysis data collected at Roodeplaat, were used to determine specific crop growth parameters for six winter vegetables and 19 varieties of summer vegetables. Guidelines for the determination of vapour pressure deficit corrected dry matter-water ratio, radiation conversion efficiency, specific leaf area, leaf-stem dry matter partitioning parameter, canopy extinction coefficient for solar radiation, maximum rooting depth and growing day degrees for the completion of phenological stages, are given in this study.

Weather data and canopy cover measurements obtained in the field trial at Roodeplaat were used to determine FAO crop factors for vegetables, and include them in the SWB database. Guidelines for the determination of FAO basal crop coefficients and length of growth stages are also given in this study.

Field measurements obtained in the Hatfield trial, were used to determine FAO basal crop coefficients and growth periods for first and second leaf peach trees.

Independent data sets obtained from South African researchers and organizations, were used to validate the model.

Simulations were carried out for agronomic, vegetable and tree crops, using both the crop growth and FAO-type model. Reasonable predictions of soil water deficit, root depth, leaf area index, total above ground and harvestable dry matter were obtained with SWB. Differences in crop water use and growth were observed for different cultivars. The crop growth model proved to be suitable for deficit irrigation simulations. Soil water deficit predicted with the FAO-type model was generally higher than that calculated with the crop growth model under water stress conditions, as the FAO model does not account for smaller canopy size. Caution should be exercised against blind acceptance of the FAO parameters as local conditions, management and cultivars are likely to influence crop growth periods and basal crop coefficients. They should, however, give a reasonable first estimate of the behaviour of the system.

The following improvements to SWB have been made:

i) Conversion of the old DOS version of the model to the efficient 32 bit Delphi Windows 95 version.

ii) "Marriage" of the mechanistic soil water balance model to the FAO basal crop coefficient approach. This brings with it the advantage of immediate inclusion of several new crops into SWB's crop database. The parameters for these crops are available from international research on updating FAO 24 (Doorenbos and Pruitt, 1992; Smith, 1992a; Allen et al., 1996).

iii) The standardized FAO Penman-Monteith grass reference evapotranspiration was included in SWB, as well as standardized options for estimating missing weather data (Smith, 1992b; Smith et al., 1996).

iv) Estimation of yield with the FAO model under conditions of water stress.

v) Calculation of the soil water balance when only a fraction of the surface is wetted (micro- or drip irrigation).

vi) Calculation of non-instantaneous drainage.

The user-friendly interface, on-line help tool, range and error checking, as well as comprehensive output graphs should allow the user to easily make real-time use of the output results. The context sensitive help tool describes how to operate the model (enter input data, run simulations, and print or create results and recommendations) and most of the technical procedures used by SWB to estimate crop growth and calculate the soil water balance. Recommended ranges for input data and general information are also given.

Product

SWB (Version 1.0) is available for use with Windows 95 on an IBM-PC or compatible computer. The minimum requirement is 16 Mb RAM . The program is supplied in executable code on 3.5-inch disks or CD, including a comprehensive user's guide and technical manual. Copies of the program are available through John G. Annandale, Dept. Plant Production and Soil Science, Univ. of Pretoria, 0001 Hatfield, South Africa (e-mail address: annan@scientia.up.ac.za).

The cost of the CD and user's guide and technical manual is R500, if SWB is used for commercial purposes. Bona fide researchers and government extension officers are charged R100 to cover duplication costs.

The source code of the model is available from Dr N Benadé. All data presented in this report are stored in the databases of SWB.

The following special features are included in the model:

i) A stand-alone ETo calculator which allows one to calculate the FAO Penman-Monteith grass reference evapotranspiration without running SWB.

ii) Soil water deficit can be calculated from measurements with the neutron water meter using the neutron probe scheduler as a stand-alone tool.

iii) Soil water deficit can be calculated from measurements with tensiometers using the tensiometer scheduler as a stand-alone tool.

iv) Soil water deficit can be calculated from measurements of gravimetric soil water content using the gravimetric scheduler as a stand-alone tool.

v) Volumetric soil water content at field capacity and permanent wilting point can be calculated from the percentage silt and clay, using empirical equations calibrated for soils in the Free State.

vi) Simulated values of fractional interception of radiation and volumetric soil water content can be updated real-time with measured data. In order to facilitate the estimation and update of fractional interception of radiation (canopy cover), a database of photos of crops at different phenological stages was included in the help file.

vii) Recommendations for irrigation scheduling are created and can be printed in SWB.

viii) A database of specific crop growth parameters and FAO crop factors is included in SWB.

ix) An address database is available.

x) Weather data can be imported into SWB from comma delimited, tab delimited or space delimited files. The order in which the data appear in the file can be specified, so standardization of data files is not important. While importing weather data, the program checks for data out of range.

Technology transfer

The main target group includes farmers as well as irrigation officers and consultants. Several commercial farmers and irrigation officers are already using or are planning to use SWB for real-time irrigation scheduling. Small-scale commercial farmers are also potential users, as well as small-scale subsistence farmers, provided they are advised by irrigation officers.

The model needs to be used extensively in the field now so that users can give valuable feedback as to it's user-friendliness and accuracy.

Conclusions and needs for further research

The revised objectives of the project have been met. A database for most crops commonly irrigated in South Africa was generated and included in SWB. A user-friendly irrigation scheduling tool was created that can be applied in practice.

Further research needs concern the introduction of specific crop growth parameters for cotton and some important tree crops. Different cultivars for crops already existing in the SWB database could also be included. Crop growth parameters refinement should be ongoing.

Deficit irrigation strategies can be accurately simulated with the mechanistic crop growth model. An economic subroutine can therefore be included in SWB in order to facilitate economic optimization target yields and irrigation strategies.

Specific requirements for some crops can be included in SWB. For example, irrigation scheduling of factory tomato and tobacco for yield and quality optimization can be modelled. Photoperiod should be included in SWB for crops like potatoes. Existing specific crop growth models can be merged to SWB in order to obtain more accurate simulations of the soil water balance and crop growth. A two-dimensional soil water balance and energy interception model is needed to predict water requirements of trees accurately.

Inclusion of a nitrogen balance will also assist irrigators quantifying possible N leaching and crop N requirements. Other useful additions include taking electricity tariffs (ruralflex) into account when recommending irrigations. Due to the fact that weather data is already in the database, disease, insect and frost warnings can also be added to make the tool even more valuable to the producer.

Agricultural development can be enhanced by making seasonal rather than real-time estimates with SWB available to farmers that do not own an automatic weather station and computer.

ACKNOWLEDGEMENTS

The research in this report emanated from a project funded by the Water Research Commission and entitled:

"Facilitating Irrigation Scheduling by Means of the Soil Water Balance Model".

The Steering Committee responsible for this project, consisted of the following persons:

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The financing of the project by the Water Research Commission and the contribution of the members of the Steering Committee is gratefully acknowledged.

The project team also thanks:

- Dr M Hensley (Institute for Soil, Climate and Water - Agricultural Research Council, Glen),
- Prof S Walker (University of the Orange Free State, Bloemfontein),
- Dr TP Fyfield (Institute for Soil, Climate and Water - Agricultural Research Council, Pretoria),
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- Ms T Volschenk (Agricultural Research Council - Infruitec, Stellenbosch)
- Mr FC Olivier (Institute for Soil, Climate and Water - Agricultural Research Council, Pretoria),
- Mr A Nel (Grain Crops Research Institute - Agricultural Research Council, Potchefstroom), and
- Dr GC Green and Mr HM du Plessis (Water Research Commission)

who made data for this study available.

The research team also acknowledges:

- Mr W van Wyk (Department of Agriculture - Directorate of Plant and Quality Control) who made available his field trial at Roodeplaat, and was responsible for crop management (plant protection, fertilization and weed control),

- Mr NC Mhlauli (Gauteng Department of Agriculture) and Mr AJ van der Westhuizen for their help in collecting field data,
- Mr Dup Haarhoff (South-West Cooperative, Kimberley), Ms H van Zijl (Department of Water Affairs, Pretoria), Mr B Swart (South African Sugar Association) and Ms D. Marais (University of Pretoria) for their interest and advice.