

TCorn : A Computer Model Simulating Maize Transpiration

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Abstract

TCorn is a computer model simulating maize transpiration. It is based on the Penman-Monteith equation and it attempts to overcome the limitations of crop coefficients by allowing a higher time resolution and working on a lower level of aggregation. At the core of the model is a routine which scales stomatal responses to light from leaf to canopy level. It assumes stable soil moisture supply. The paper gives a brief outline of the simulation procedures and describes the operation of the model.

Introduction

During major parts of the growth cycle, water use of field crops is governed by transpiration. Accurate information about this variable is crucial in the determination of efficient application of irrigation water. Crop coefficients (Doorenbos and Pruitt 1977), which are commonly used to convert potential evapotranspiration to actual crop water use, are not capable of capturing the complex and flexible interactions between rapidly changing environments and the physiological responses thereto. A new method just being proposed by the FAO refines the determination of crop water requirements by distinguishing between different components of evapotranspiration (Smith et al. 1996; Allen et al 1999). However, it still relies on two empirical factors (K_{cb} and K_e) which account for a large number of underlying processes.

TCorn is a computer model simulating maize transpiration. It is based on the Penman-Monteith equation and it attempts to overcome the limitations of crop coefficients by allowing a higher time resolution and working on a lower level of aggregation. At the core of the model is a routine which scales stomatal response to light from leaf to canopy level (Langensiepen 1996). It is based on a light penetration model and assumes stable soil moisture conditions. Other parameters were chosen following standard procedures.

The model was built to provide an agrometeorological network tool to assess irrigation needs of maize plantations grown under sub-tropical conditions in Southern Brazil. It was verified under different climate conditions using the heat-pulse method for measuring sap-flow (Cohen et al. 1988; Cohen and Li 1996) as a standard reference.

The purpose of this paper is to give a brief outline of the simulation procedures and to describe the operation of the model. Detailed background information can be found in Fuchs et al. (1987) and Langensiepen (1997).

Brief Outline of Simulation Routines

Daily computations are initialized by the determination of the astronomical position of the earth on its sun orbit, a variable, which is later used to resolve sun zenith and azimuth angles depending on local time and earth rotational speed. It uses a Fourier series expression to determine sun declination (Spencer 1971). Sun zenith and azimuth angles are calculated at any given time of the day using standard expressions of spherical trigonometry. Computations of maximum possible shortwave radiation (Campbell 1977) are set into a relation with measured solar radiation to determine sky cloudiness, a variable, which is later used to estimate longwave radiation exchange (Fuchs 1993). The attenuation of radiation fluxes is modeled using information on leaf angle and density distributions. Random leaf azimuth orientation and horizontal homogeneity in each canopy layer are assumed. If data on geometric orientation are not available, the simulation can be simplified to a spherical leaf angle distribution problem. The extinction of direct shortwave radiation is calculated using expressions taken from the SAIL model (Verhoef 1984). Attenuation of diffuse radiation fluxes is computed by integrating the interception probabilities over all sky angles.

Atmospheric conditions are assumed to be neutral and heat and mass transfer are considered to take place under forced convection. Turbulent transfer is treated analogous to molecular diffusion (k-theory). The corresponding coefficients were taken from the literature (Tolk et al. 1995; Thom 1975; Garrat and Hicks 1973). The exchange of fluxes is scaled to a canopy height which is the sum of displacement height and roughness length ("big leaf"). Aerodynamic and boundary layer resistances are connected in series. Leaf resistances are connected in parallel. The canopy resistances were derived from the radiation model using empirical relations between light interception and leaf conductances. They were determined at defined soil moisture conditions. Transpiration is calculated separately for the sunlit and shaded leaf fractions taking into account their different exchange heights ("Two big leaves").

User Interface

The program is packaged in a self-extractable file "TCornIns.exe", which has to be copied into any empty subdirectory. Running this file will cause the program to install itself into this directory.

A graphic user interface will be loaded upon program start. Its opening screen (Fig.1) acknowledges the contribution from the GIARA program and gives the contact addresses of the principal investigators. The left hand side of the screen is filled with several push buttons accessing the input masks which need to be filled with information to run the program. A traffic light (red, yellow and green colors) is positioned in the left screen corner to give a basic idea whether the program is ready for execution. Missing information will cause the traffic light to turn red and the "RUN" button will be disabled. Pushing the F1-key or the help button opens the help-system (Fig. 2). Menu driven commands are displayed in the language of the Windows version being installed.

The model needs two types of input files (File screen - see Fig. 3). One file will come directly from the weather station (Meteorological station file) and the other (*.OPT files) carries all information on file structuring, station parameters and plant characteristics (Runtime parameters). These files can be accessed by clicking the corresponding radio buttons and by setting directory and file paths. The path of the output file (Simulation output) can be chosen, as well, but its name has to be entered manually. This is to ensure that the user does not accidentally overwrite any other file and really wants to name the file as such. No questions (Do you really want to overwrite ? Yes/No) will be asked when a file is overwritten. This will

Deutscher Tropentag 1999 in Berlin
Session: Information and Communication Technology for Rural Development

speed up processing when working with large volumes of data. After pushing the run button all input and output data are automatically processed as requested and the header of TCorn's Windows screen will show the final results (e.g. Daily Potential and Actual Crop Water Use). The parameter file specified in „Runtime parameters“ is updated each model run.

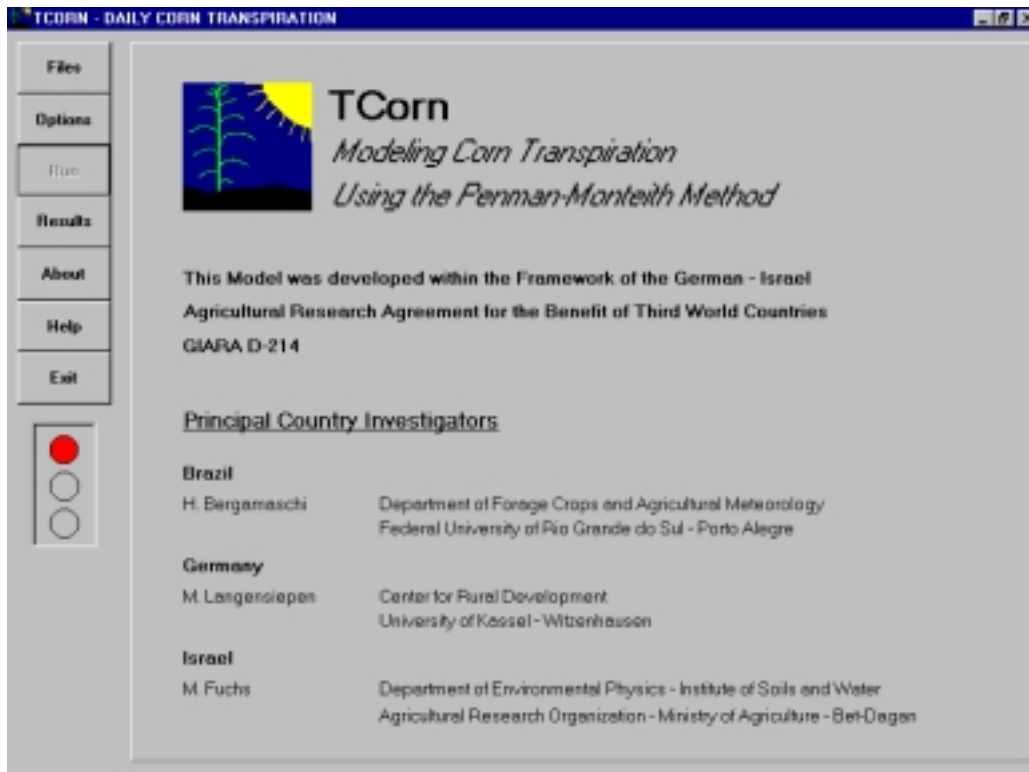


Fig. 1 Opening screen

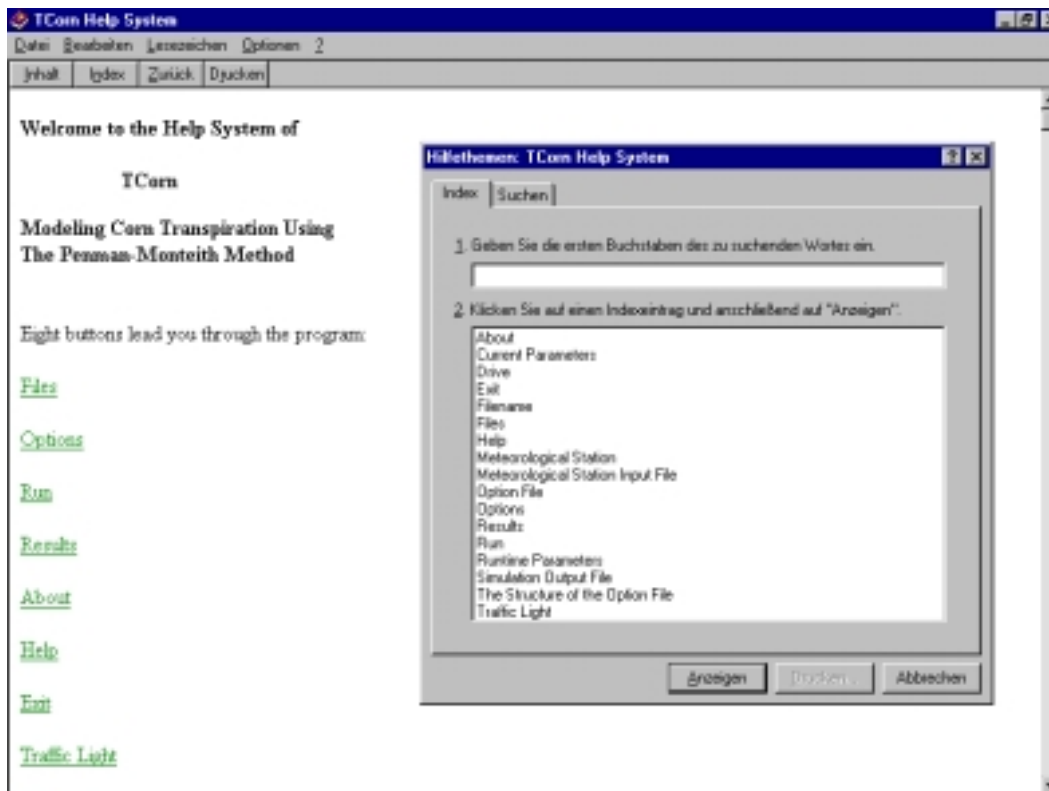


Fig. 2 Help-System

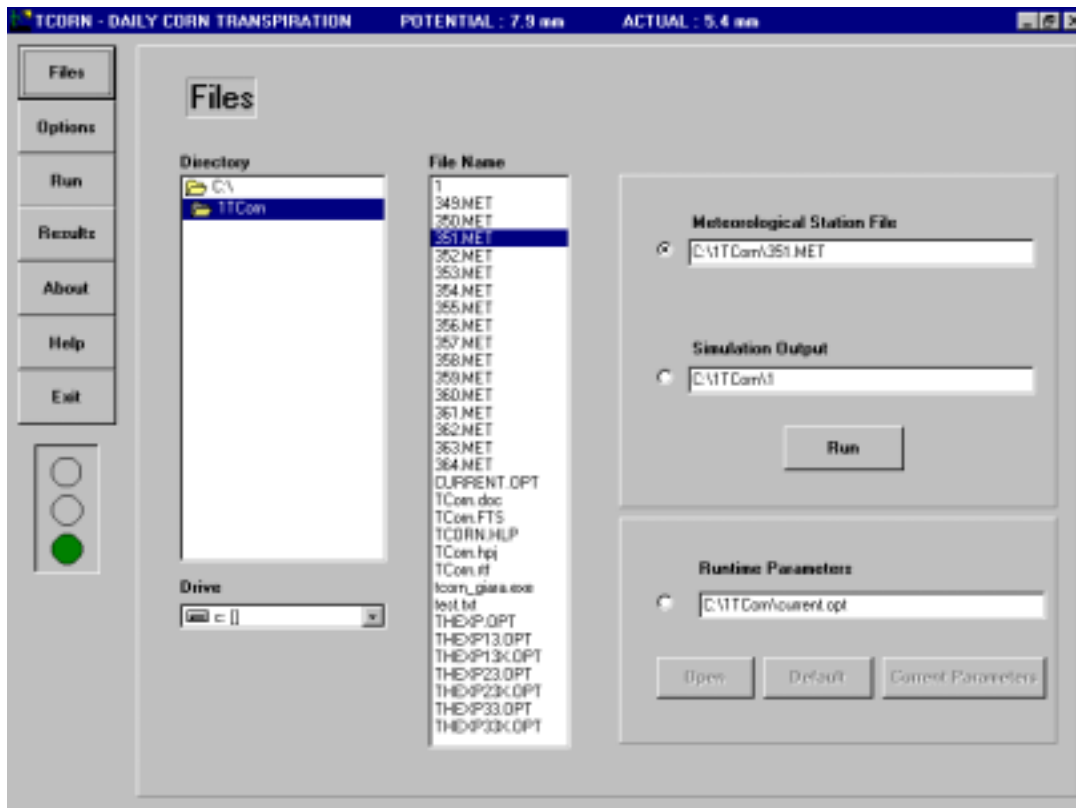


Fig. 3 File Access

Upon first model application, the user needs to give information about the structuring of the input and output files. This procedure was designed in a way to allow maximum flexibility and easiness of data handling. There is no need to define spacing or separators. The only information which is necessary to be entered into the flip panel “—> Meteorological Station Input File“is the sequence of meteorological data associated with the time stamp (Fig.4). Any common date and time format can be used and numerical values have to be in real number format using international notation (e.g. decimal numbers are separated by a dot, for example 23.21 and not by a comma like 23,21). The meteorological station file should only carry numerical values. Time stamps with their associated data sets should fill each a separate line. The current model version processes daily files, but can be easily extended to handle seasonal data.

The structure of the output file can be selected in the “—> Simulation Output File panel“. Possible choices encompass weather station recordings, transpiration calculations, as well as determinations of energy budget, canopy conductance and distribution of net radiation. Data can be dumped in comma delimited or fixed spaced output format. Pre-determined headings of the subsections simplify navigation in case model outputs are further processed with a database engine.

Further information is needed on the location, the sensor heights and the recording interval of the meteorological station. It may happen that a sensor needs to be calibrated against a standard reference instrument. The program provides four cubic polynomials for this purpose. However, the corresponding input window will be only opened after pushing an OK button ensuring that this tool is not used as a fudge factor.

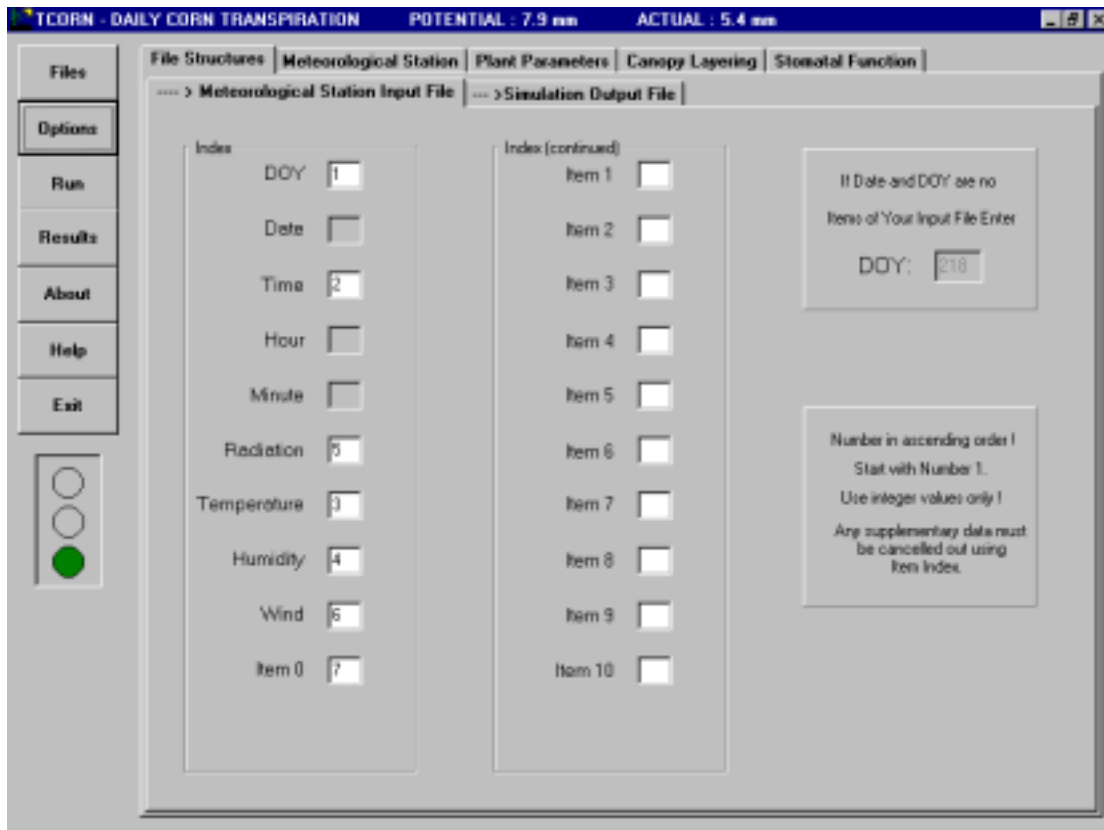


Fig. 4 Flip panel “— > Meteorological Station Input File“

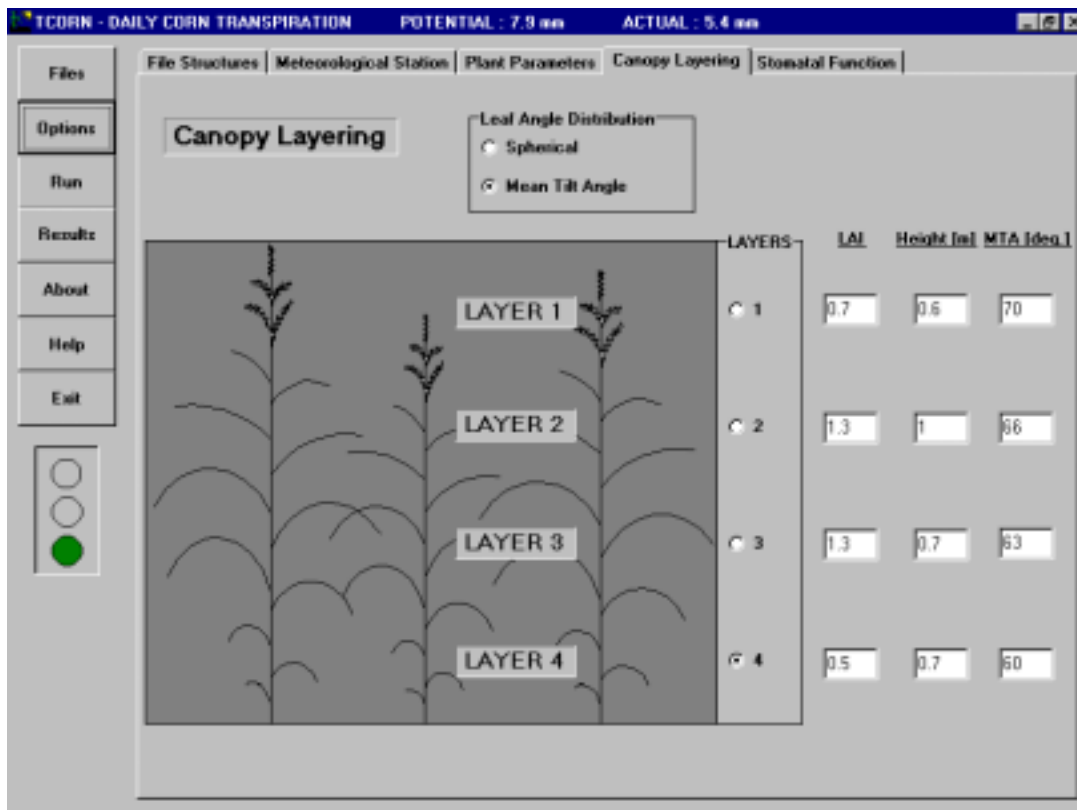


Fig. 5 Input panel for entering canopy parameters

Next flip-panel “Plant Parameters“ serves as input for standard plant parameters. Leaf reflectance and transmittance, as well as the optical air mass number have been set to standard values that apply to many practical situations. Edit boxes are located on the right hand of the panel in case these values need to be changed.

Entering information on leaf area index and plant height can be handled in various ways. In case the simulation of radiation distribution is confined to one canopy layer, both values can be entered manually in the corresponding edit fields. This can become a tedious task when working on seasonal data sets. Instead, both data can be computed from seasonal time using cubic polynoms and by enabling a corresponding checkbox.

The model is able to process information from up to four different layers. A panel “Canopy Layering“ has to be opened for this purpose (Fig. 5). The number of layers can be selected by checking one of the coupled radio buttons situated next to an instructive graphic screen. LAI and height information are to be entered next to each layer. The model is also able to process data of mean leaf angle distribution. If such information is not available, the model assumes a spherical leaf angle distribution.

The input of model parameters is completed by checking the „Stomatal Function“ panel (Fig. 6) and entering a stomatal light response function. Square root or hyperbolic function types may be selected and an editing section allows placement of comments on plant water status.

All model parameters are stored in an option (*.opt) file, which needs to be named in the file input section.

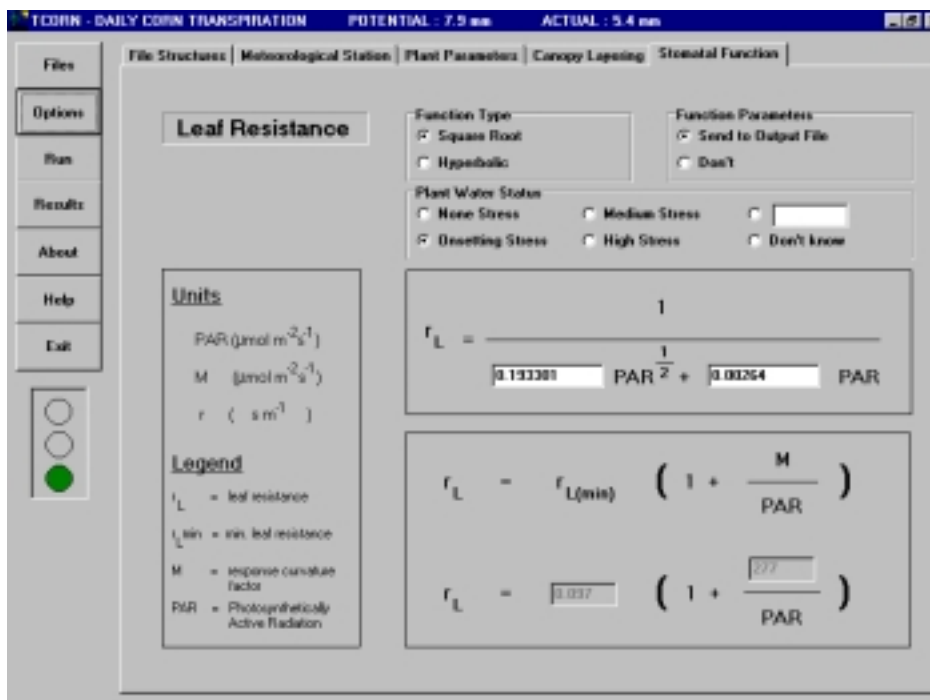


Fig. 6 Input panel for entering the stomatal light stress response function

Results of the simulation runs can be visualized using a built in graphic display. Pressing the „Result“ button will display the diurnal actual transpiration of the last simulation run (Fig.7). The screen will be empty in case there was no previous model run.

Axis margins will adapt themselves to the data series, but can be re-scaled at any time by using the pull-down menu located above the line graph. Tick labels are distributed at pre-defined intervals, but can be also reset by using the pull down menu (Fig.7).

The pull down menu offers a selection of the most important simulation outputs (Fig.8), which can be accessed by placing the mouse driven menu bar on the chosen item.

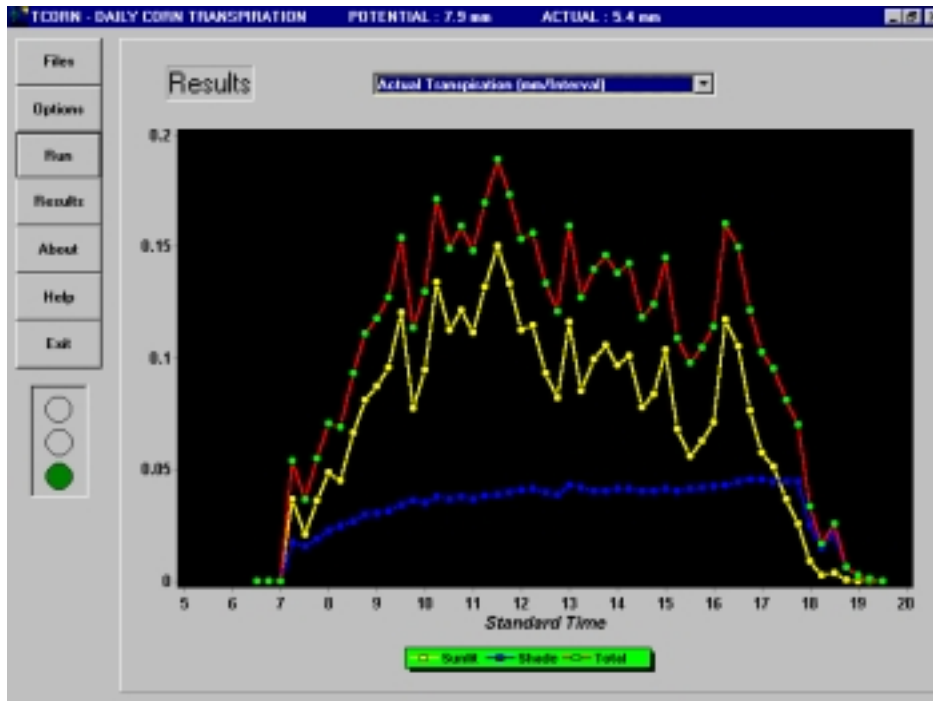


Fig. 7 “Results“ screen showing diurnal actual transpiration (default)

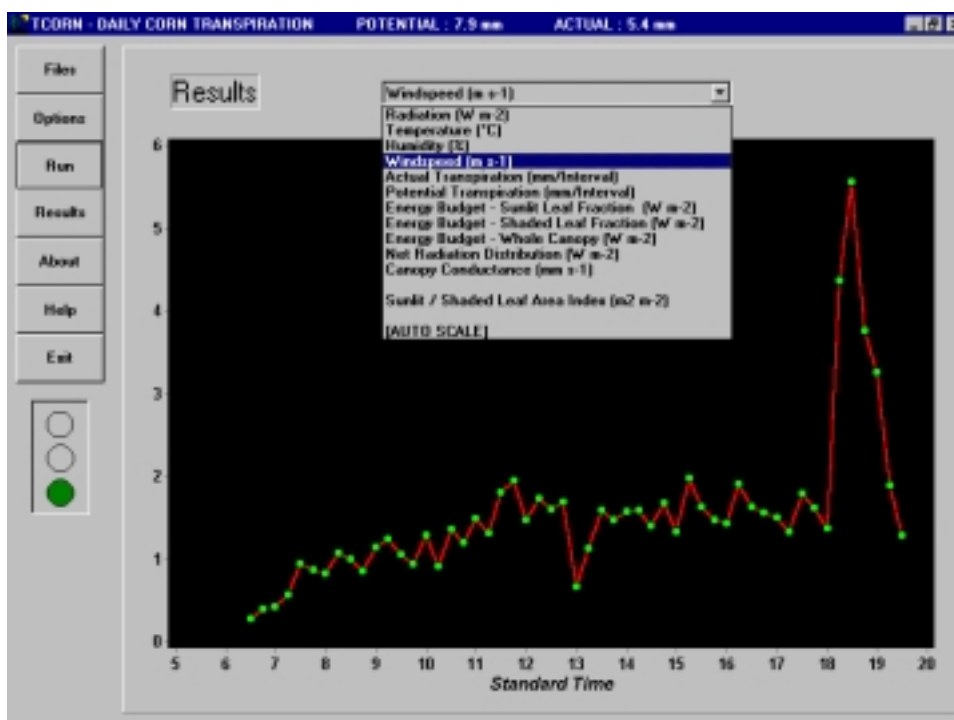


Fig. 8 Pull-down menu for accessing most important simulation outputs

Application

The model was verified under the different climate conditions of Brazil, Germany and Israel. It is ready to be used as a research and teaching tool. However, to become fully applicable under practical conditions it needs, yet, to undergo an extensive validation study. The model will be soon tested in the agrometeorological network of the Brazilian state of Rio Grande do Sul, which is currently at the stage of construction.

Literature

- Allen R. (1999) Crop evapotranspiration: guidelines for computing crop water requirements. Irrigation and Drainage Paper 56. FAO, Rome
- Campbell G.S. (1977) An introduction to environmental biophysics. Springer, Berlin
- Cohen Y., Fuchs M., Falkenflug V. and S. Moreshet (1988) Calibrated heat pulse method for determining water uptake in cotton. *Agron J.* 80: 398-402
- Cohen Y. and Y. Li (1996) Validating sap flow measurement in field-grown sunflower and corn. *J. Exp. Bot.* 47: 1699-1707
- Doorenbos J. and W.O. Pruitt (1977) Guidelines for predicting crop water requirements. Irrigation and Drainage Paper 24. FAO, Rome
- Fuchs M., Cohen Y. and S. Moreshet (1986) Determining transpiration from meteorological data and crop characteristics for irrigation management. *Irrig. Sci.* 8: 91-99
- Fuchs M. (1993) Radiative exchange and microclimate in vegetation canopies. In Varlet-Grancher C., Bonhomme and H. Sinoquet (eds.) *Crop structure and light microclimate*. INRA Publications, Paris
- Garrat J.R. and B.B. Hicks (1973) Momentum, heat and vapor transfer to and from natural and artificial surfaces. *Q. J. Royal Met. Soc.* 99: 680-687
- Langensiepen M., Bergamaschi, Cohen S., Cohen Y., Fuchs M., Moreshet S., Rosa L.M. and A.O. Santos (1996) Improved modeling of evapotranspiration by relating leaf stomatal vapor conductance to phytoactinometric plant stand characteristics: A case studies using maize. In Camp C.R., Sadler E.J. and R.E. Yoder (eds.) *Evapotranspiration and Irrigation Scheduling*. p. 685-690. Proceedings of the International Conference. Nov. 3-6, 1996. ASAE, St. Joseph, MI, USA
- Langensiepen M. (1997) Improving agrosystem management using meteorological network data: Case studies in Brazil, Germany and Israel on corn. (In German with English summary). 147 p. 59 Figs. *Der Tropenlandwirt*. Beiheft 59. Witzhausen. ISBN 3-88122-928-0
- Smith M., Allen R. and L. Pereira (1996) Revised FAO methodology for crop water requirements. In Camp C.R., Sadler E.J. and R.E. Yoder (eds.) *Evapotranspiration and Irrigation Scheduling*. p. 116-223. Proceedings of the International Conference. Nov. 3-6, 1996. ASAE, St. Joseph, MI, USA
- Spencer J.W. (1971) Fourier series expression of the position of the sun. *Search* 2: 172
- Tolk J.A., Howell T.A., Steiner J.L. and D.R. Krieg (1995) Aerodynamic characteristics of corn as determined by energy balance techniques. *Agron. J.* 87: 464-473
- Thom A.S. (1975) Momentum, mass and heat exchange of vegetation. In Monteith J.L. (ed.) *Vegetation and the atmosphere*. Vol. 1. Academic press, London
- Verhoef. W. (1984) Light scattering by leaf layers with application to canopy reflectance modelling: The SAIL model. *Rem. Sens. Env.* 16: 125-141