7 - TESTING THE IRRIGATION SCHEDULING SIMULATION MODEL ISAREG FOR COTTON AND WINTER WHEAT IN CENTRAL ASIA

E. D. Cholpankulov[1], O. P. Inchenkova [1], P. Paredes[2], L. S. Pereira[2]

Abstract: The calibration and validation of the irrigation scheduling simulation model ISAREG for Central Asia conditions was performed using field observations for cotton in Hunger Steppe over the period 1982-1988 and for cotton and winter wheat in Fergana Valley for the period 2001-2003. The calibration and validation were performed by comparing observed and simulated soil water content along the crop seasons. The crop coefficients were therefore adjusted for local conditions as well as soil hydraulic properties and the soil water depletion factor for no stress. The parametric equations for estimating the groundwater contribution were also tested and validated. In addition, the Penman-Monteith reference evapotranspiration equation was positively tested in comparison with other estimation methods formerly used. In conclusion the results obtained show a good agreement between field observations and model predictions, which allow the use of the ISAREG model to generate and assess alternative irrigation schedules aimed at improved water use in Central Asia.

Keywords: Cotton, Winter wheat, Crop coefficients, Crop water requirements, Irrigation scheduling.

Introduction

The water conservation issues were always a main concern in Central Asia countries, and water use control and monitoring were currently performed in the past by the USSR Ministry of Land Reclamation and Water Resources. Since 1992, the five New Independent States initiated a new process to share the common water resources of the Amudarya and Syrdarya rivers. This created new problems concerning the rational use of the shared water resources. Presently, there is no specific governmental agency to monitor and control the

[1] SIC ICWC B.11, Karasu-4, Tashkent, 7000187, Uzbekistan. Email: horst san@mail.ru
[2] Centre of Agricultural Engineering Research, Institute of Agronomy, Lisbon, Portugal. Email: pparedes@isa.utl.pt, lspereira@isa.utl.pt

water resources used in irrigation. Furthermore the existing methodologies for deciding on the irrigation depths and rates to be used in irrigation do not meet modern requirements because they were developed for the average water availability year without considering how target yields, climatic characteristics and irrigation method influence crop water consumption and use.

The control and monitoring of water use is very difficult in these countries since irrigated agriculture is main water consumer representing 92% of the water consumption. Problems aggravate since different method are adopted by each Republic for the definition of irrigation depths and rates, which leads to unclear assessment of the actual water supply situation in the region. The most used approaches base upon the use of Ivanov's formula for computing evapotranspiration and the calculation of irrigation norms according to national climatic conditions (Shreder *et al.,* 1977; Domullodjanov, 1983; RDMU, 1988; KIIW, 1989).

During the last decades, many scientific and technological developments occurred, including relative to information technologies. Thus, it is very important to develop a common methodological approach and indicators to assess crop and irrigation water requirements for all States located in the Aral Sea basin and to consider the use and validation of internationally adopted methodologies such as those proposed by FAO (Allen *et al*., 2001). With this purpose the ISAREG model (Teixeira and Pereira, 1992, Liu *et al*. 1998) was selected. This irrigation scheduling simulation model is being used after long time in several parts of the World for assessing crop and irrigation water requirements using weather data time series, evaluating current irrigation schedules, and selecting the most appropriate crop irrigation scheduling in relation to targets on yields and/or availability of irrigation water.

The ISAREG model permits to simulate alternative irrigation schedules relative to different levels of allowed crop water stress as well as to various constraints in water availability. The irrigation scheduling alternatives are evaluated from the relative yield loss produced when crop evapotranspiration is below its potential level. Recent examples of successful model applications to winter and summer surface irrigated crops in the Mediterranean region are presented by Oweis *et al*. (2003) and Zairi *et al*. (2003), and for surface irrigated crops in North China by Liu *et al*. (2000) and Campos *et al*. (2003).

This paper describes the main results of field and computational studies aiming at calibrating and validating the WINISAREG version of the ISAREG model in Central Asia for main irrigated crops in the region, cotton and winter wheat, including the derivation of crop coefficients.

The model

The ISAREG model is an irrigation scheduling simulation model that performs the soil water balance at field level (Fortes *et al*., 2005). The water balance is performed for a multilayered soil. Depending on weather data availability, various time step computations can be used. Input data include precipitation, reference evapotranspiration, total and readily available soil water, soil water content at planting, potential groundwater contribution, crop coefficients and soil water depletion fractions for no-stress relative to crop growth stages, root depths and the water-yield response factor.

The model computes the actual evapotranspiration (ET_a) from the potential crop evapotranspiration, which is defined by

$$ET_c = K_c \, ET_o \qquad [1]$$

thus from the reference evapotranspiration (ET_o, mm) and the crop coefficients (K_c). ET_a is estimated as a function of the available soil water in the root zone when depletion exceeds the depletion fraction for no stress (p).

Irrigation depths and dates may be selected in accordance with different objectives and are computed according to water depths limits and soil water thresholds defined by the user. The water stress impact on crop yield is evaluated by the model proposed by Stewart *et al*. (1977) where relative yield losses depend upon the relative evapotranspiration deficit through the water-yield response factor K_y.

The recent Windows version of the model, WINISAREG, is described by Pereira *et al*. (2003) and Fortes *et al*. (2005), the later also referring to the GIS version, GISAREG. In the WINISAREG version the crop parameterization program KCISA (Rodrigues *et al*., 2000) and the ET_o computation program EVAP56 are integrated with ISAREG. It is also included an algorithm that takes into consideration the soil salinity impacts on ET_c and yields (Campos *et al*., 2003) and an algorithm for computation of the groundwater contribution (Gc) and percolation (Liu *et al*., 2001) where Gc is a function of the groundwater table depth, soil water storage, soil properties influencing capillarity, and ET_c. Percolation resulting from excess water in the root zone is estimated by a parametric equation as a function of soil characteristics and the amount of water in excess to field capacity (Liu *et al*., 2001).

The model input data can be provided at run-time by the keyboard or trough pre-defined ASCII files referring to:

- *Meteorological data* concerning precipitation, P (mm) and reference evapotranspiration, ET_o (mm), or weather data to compute ET_o with the FAO-PM methodology, including with missing climate data (Allen *et al*., 2001);
- *Crop data* referring to dates of crop development stages, crop coefficients (K_c); root zone depths Z_r (m); soil water depletion fractions for no-stress (p); and the seasonal water-yield response factor (K_y);

- *Soil data for a multi-layer soil*; relative to each layer, the respective depth d (m); the soil water content at field capacity θ_{FC} (mm mm^{-1}) and the wilting point θ_{WP} (mm mm^{-1}); an additional file is used to input the parameters of the equation relative to groundwater contribution.

The model is prepared for calculations under conditions of frozen soil with crop planting before soil freezing or after melting. The initial soil water content is provided by the user or from estimations performed by simulating a previous period of fallow, which simulation starts at the end of the dry season, when most of the soil water is consumed, or during the wet season when replenishment of the soil water may be assumed. Examples of these procedures are presented by Campos *et al*. (2003).

The ISAREG model computes the capillary rise from the water table applying the equations presented by Liu *et al* (2001). The parametric equations used to compute the groundwater contribution G (mm d^{-1}) are the following:

$$G = G_{max}(D_w, ET_m) \qquad W < W_s(D_w)$$

$$G = G_{\max}(D_w, ET_m)\left(\frac{W_c(D_w) - W}{W_c(D_w) - W_s(D_w)}\right) \qquad Ws(Dw) \le W \le Wc(Dw) \qquad [2]$$

$$G = 0 \qquad W > Wc(Dw)$$

where D_w is the groundwater depth; W, W_s and W_c are respectively the actual, steady and critical soil water storage, ET_m is the potential or maximal crop evapotranspiration and G_{max} is the potential or maximal G for this type of soil and climate.

The function G_{max} (D_w , ET_m) is given by

$$Gmax = k \cdot ETm \qquad when\ Dw \le Dwc \qquad [3a]$$

$$Gmax = a_4 \cdot Dw - b_4 \qquad when\ Dw > Dwc \qquad [3b]$$

where k is an empirical constant depending on the soil type (Table 1) and D_{wc} is the critical value for D_w given by

$$D_{wc} = a_3 \cdot ET_m + b_3 \qquad \text{when } ET_m \le 4\ mm/d \qquad [4a]$$

$$D_{wc} = 1.4 \qquad \text{when } ET_m > 4\ mm/d \qquad [4b]$$

The function W_c (D_w) is given by

$$W_c = a_1\, D_w^{-b_1} \qquad [5]$$

and $W_s(D_w)$ is

$$W_s = a_2 \cdot D_w^{b_2} \qquad for\ D_w \le 3m \qquad [6a]$$

$$W_s = 240\ mm \qquad for\ D_w > 3m \qquad [6b]$$

The percolation fluxes are computed with the decay equation

$$W = a \cdot t^{b} \qquad [7]$$

where W (mm) is the soil water storage at time t (day) after an heavy rain or irrigation; and a, b are constants that depend on the soil characteristics. The parameter a is between soil water storage at saturation and field capacity and b is smaller than –0.017 for soils draining quickly and larger for soils with slow drainage.

Table 1. Summary of equations used to compute the groundwater fluxes and respective parameters.

Equations	Conditions	Parameters
$W_c = a_1 \cdot D_w^{b1}$		a1 = W_{Fc}, the soil water storage to 1.0 m depth at field capacity b1 = -0.17
$W_s = a_2 \cdot D_w^{b2}$		a2 = 1.1 (W_{Fc} + W_{Wp})/2, a storage above the average between those at field capacity and the wilting point b2 = -0.27
$D_{wc} = a_3 \cdot ET_m + b_3$	When $ET_m \leq 4$ mm/d	a3 = -1.3
$D_{wc} = 1.4$	When $ET_m > 4$ mm/d	b3 = 6.7 for clay and silty clay loam soils, decreasing to 6.2 for loamy sands
$G_{max} = k \cdot ET_m$	When $D_w \leq D_{wc}$	a4 = 4.6 for silty loam and silty clay loam soils, decreasing to 3 for loamy sands
$G_{max} = a_4 \cdot D_w^{b4}$	When $D_w > D_{wc}$	b4 = -0.65 for silty loam soils and decreasing to –2.5 for loamy sand soils
$k = 1 - e^{-0.6 \cdot LAI}$	When $ET_m \leq 4$ mm/d	
$k = 38/ETm$	When $ET_m > 4$ mm/d	

Several field and computer studies were performed to adapt the models for the Central Asia conditions, including for estimating the groundwater contribution. On the one hand, observations formerly performed in the state farm "Fergana", Syrdarya oblast, Hunger Steppe, Uzbekistan, for the period 1982 – 1988 (Cholpankulov *et al.,* 1984, 1986, 1991, 1992; Cholpankulov and Ikramov, 1995) were used to calibrate the model to those conditions, including a comparison of methods to estimate the reference evapotranspiration, derivation of the crop coefficients and depletion fractions for no stress. On the other hand, a set of field experiments were established in Fergana Valley at Fergana oblast (state farm "Azizbek-1"), Uzbekistan, and at Osh oblast (state farms "Sandik" and "Toloikon"), Kyrgyzstan, (Cholpankulov and Inchenkova, 2002, Cholpankulov *et al*., 2004), where similar model calibration was performed.

Material and methods

Case study relative to the Hunger Steppe

The Hunger Steppe is located on the left bank of the SyrDarya river and consists of a vast depression limited by the Turkestan and Nuratau ridge in the

South and the Chatkal ridge in the East. The Western boundary runs along the ancient channel Arnasai separating the Hunger Steppe from the Kyzylkum desert. In the East and North-east the SyrDarya river separates the Hunger steppe from the Dalverzin Steppe and Tashkent oasis. The experimental area is located in the "Fergana" state farm, Syrdarya oblast (40.2º N, 68.6º E and 332 m elevation).

The climate of this region is continental arid, with low cloudiness, and with high temperatures in the summer and low temperatures in the winter. The precipitation occurs mainly during the winter season. The maximum temperature occurs in July (up to 47 ºC) and the minimum by December-January (-34^0 C). The annual precipitation varies within 250-300 mm but reaching 430 mm where closer to mountains. The climatic characterization for the cotton crop season (April-September) for the period 1982-88 is presented in Fig. 1 and 2 and Table 2.

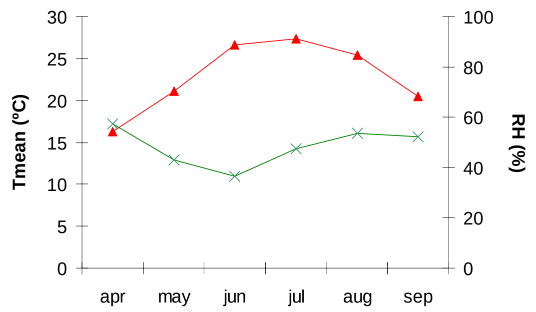


Fig. 1. Hunger Steppe, 1982-88: Average monthly temperature (▲) and relative humidity (×).

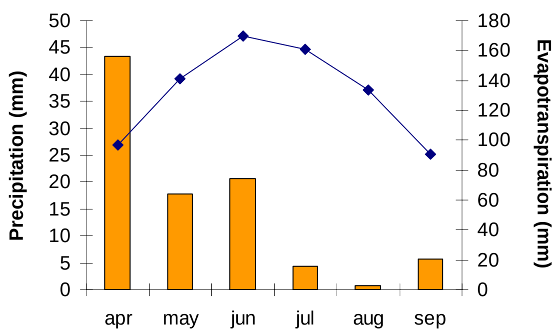


Fig. 2. Hunger Steppe, 1982-88: Average monthly precipitation (■) and average monthly reference evapotranspiration (ETo) (◆).

Cotton ET values were determined from field research conducted on cotton over 1982-1988 (Cholpankulov *et al.*, 1992) using the energy balance method (Anon., 1977), which simplified equation may be written as:

$$E = CF\,(R - B - Q) \qquad [8]$$

where E is cumulative evaporation (mm) or latent heat flux, R is radiation balance (cal/cm^2) or net radiation, B is heat flux to the soil (cal/cm^2), Q is turbulent heat exchange (cal/cm^2) or sensible heat flux, and CF is the conversion factor relative to units and time scale of observations.

Table 2. Average ($\overline{X}$) and standard deviation (s) relative to main meteorological data ("Fergana" state farm, Syrdarya, Hunger Steppe, 1982-88).

		Apr	May	Jun	Jul	Aug	Sep
T_{mean}	$\overline{X}$	16.3	21.1	26.6	27.3	25.4	20.4
[ºC]	s	*1.5*	*2.4*	*0.9*	*1.7*	*1.4*	*1.2*
RH	$\overline{X}$	58	43	37	48	54	52
[%]	s	*8.8*	*6.9*	*5.4*	*10.2*	*9.3*	*10.6*
u_z	$\overline{X}$	2	2	1.5	1	1	1
[m s^{-1}]	s	*0.6*	*0.5*	*0.4*	*0.4*	*0.4*	*0.5*
n	$\overline{X}$	7.3	9.4	10.5	10.7	9.8	8.2
[h]	s	*1.2*	*1.9*	*3.3*	*4.4*	*4.2*	*3.1*
ET_o	$\overline{X}$	3	5	6	5	5	3
[mm d^{-1}]	s	*0.4*	*0.5*	*0.7*	*1.0*	*1.0*	*0.5*
P	$\overline{X}$	44	18	21	4	1	6
[mm]	s	*34.4*	*9.7*	*26.7*	*6.7*	*1.8*	*6.5*

The radiation balance and the heat flux to the soil were measured in the field with sensors developed at the Leningrad Agrophysical Institute. For temperature and air humidity observations at 2.0 and 0.5 m heights, when (R-B) > 0.2 cal/cm^2 min, $\Delta T \geq 0.3$ ºC ($\Delta T = T_{0,5} - T_{2,0}$) and $\Delta e \geq 0.3$ mbar ($\Delta e = e_{0,5} - e_{2,0}$), the turbulent heat exchange is estimated by:

$$Q = (R\text{-}B)\,\Delta T / (\Delta T + 1.56\,\Delta e) \qquad [9]$$

or, when the above mentioned condition is not fulfilled, by

$$Q = 1.35 * K * \Delta T \qquad [10]$$

where K is a turbulence coefficient characterizing the intensity of vertical heat transport. *K* is given by

$$K = 0.104 * m * \Delta u \qquad [11a]$$

$$K = 0 \qquad \text{if } \Delta T < -2.0\ ºC \text{ or } \Delta u < 0.3 \text{ m/s} \qquad [11b]$$

where Δu is difference between wind speed (m s^{-1}) observed at 2.0 and 0.5 m heights, and *m* is a value depending on the Richardson number:

$$m = 1 + 2.6\,Ri + \text{sqrt}\,((1+2.6\,Ri)^2 - 1) \quad \text{if } Ri \leq 0 \qquad [12a]$$

$$m = 1 + 10.3\,Ri - \text{sqrt}\,((1+10.3\,Ri)^2 - 1) \quad \text{if } Ri > 0 \qquad [12b]$$

with

$$Ri = -\,0.048\,\Delta T / (\Delta u)^2 \qquad [13]$$

The related field observations included air temperature (measured at a height of 2 m and 0.5 m), relative air humidity (RH) and wind speed (measured at the same heights), and radiation balance measured at 2 m. Those observations were made every 3 hours. Daily temperature and RH data were also observed in a nearby weather station to compute the potential ET with the Ivanov's equation (Ivanov, 1957; Sredazgiprovodkhlopok, 1970):

$$ETp = 0.0018\,(T+25)^2\,(100 - RH) \qquad [14]$$

where ETp (mm) is potential evapotranspiration, T (ºC) is the average monthly temperature and RH (%) is the average monthly air humidity. Daily observations of the potential evaporation were performed with the GGI-3000 evaporation pan.

Observations of the water table depth and soil moisture were also performed, the later down to the water table depth using the gravimetric method. These were made once a 10-day period. The irrigation inflow rates and volumes applied to the experimental fields were measured with a Cipolletti weir.

The hydraulic proprieties of the soils in the area are shown in Table 3. Differences in their characteristics along the years of study are due to the fact that the experiments took place in different fields.

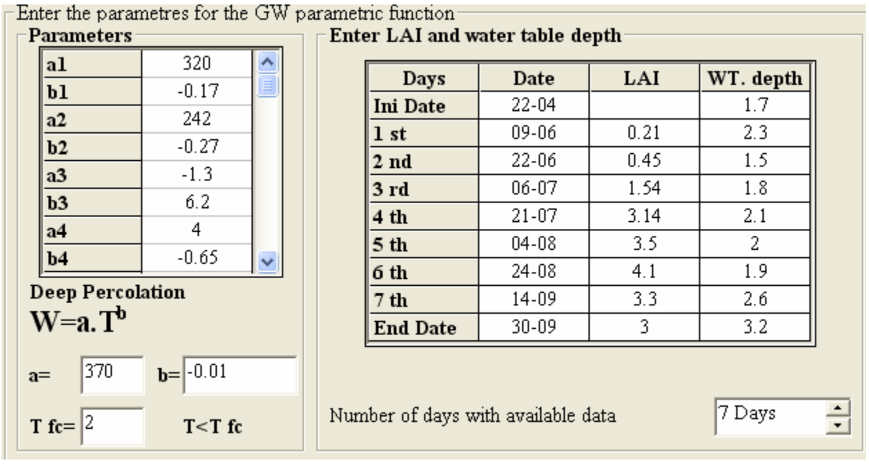
Table 3. Field capacity, wilting point and total available water (TAW) of the soils in experimental plots, 1982-87, Hunger Steppe.

	θ_{Fc} (m^3/m^3)	θ_{Wp} (m^3/m^3)	Zr (m)	TAW (mm/m)
1982	0.37	0.13	2.00	240
1983	0.32	0.11	1.50	210
1984	0.30	0.10	1.50	200
1985	0.31	0.8	1.50	230
1986	0.28	0.11	1.20	130
1987	0.31	0.11	1.50	200

The groundwater table depths were studied at field level for the period 1983-88. However, no data are available for the years 1986 and 1988. From those former studies, it was concluded that the groundwater table depths in the Hunger Steppe case study varied within 1.2 and 3.2 m during the cotton growing season depending on the number of irrigations practiced in the area and less on rainfall.

Taking into consideration the soil hydraulic properties of the Hunger Steppe soils, the values considered for the groundwater contribution parameters listed in Table 3 for the Hunger steppe location are as follows: a_1 = 320; b_1 = -0.17; a_2 = 242; b_2 = -0.27; a_3 = - 1.3; b_3 = 6.2; a_4 = 4 b_4 = -0.65. The parameters of the percolation equation (7) are a = 370 and b = -0.01 and it was considered that field capacity was attained 2 days after the heavy surface irrigation applications.

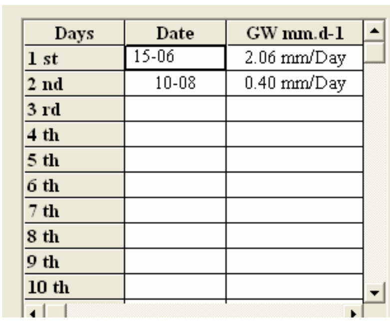
The computations of the groundwater contribution using the ISAREG model were made for the period 1982-88 (Fig. 3). The exception was the computation made for 1982 and 1986 were in this case the computation used was the option 2 (Groundwater varies throughout the irrigation period) presenting the potential GW contribution in specific dates (Fig. 4).



a1	320
b1	-0.17
a2	242
b2	-0.27
a3	-1.3
b3	6.2
a4	4
b4	-0.65

Days	Date	LAI	WT. depth
Ini Date	22-04		1.7
1 st	09-06	0.21	2.3
2 nd	22-06	0.45	1.5
3 rd	06-07	1.54	1.8
4 th	21-07	3.14	2.1
5 th	04-08	3.5	2
6 th	24-08	4.1	1.9
7 th	14-09	3.3	2.6
End Date	30-09	3	3.2

Fig. 3. WINISAREG window showing the parameters used to compute the groundwater contribution and the water table depths for 1983 in the Hunger Steppe.



Days	Date	GW mm.d-1
1 st	15-06	2.06 mm/Day
2 nd	10-08	0.40 mm/Day
3 rd		
4 th		
5 th		
6 th		
7 th		
8 th		
9 th		
10 th		

Fig. 4. Groundwater contribution computation window relative to WINISAREG option 3, Hunger steppe, 1986.

Case study relative to the Fergana Valley

The Fergana Valley region is divided among Uzbekistan, Tajikistan and Kyrgyzstan. It is located in southwestern part of the Tian-Shan mountain system. The SyrDarya river separates the valley into two parts, from which the southern one is the largest one and where the experimental areas are located ("Azizbek-1", "Sandik" and "Toloikon" state farms). The Valley is bordered with Fergana ridge in the East, Alai and Turkestan ridge in the South and Chatkal-Kurama ridge in the North. The Fergana Valley is drained by the SyrDarya river and by numerous mountain streams that are fed by the glaciers in the mountains. Major cities in the valley include Fergana, Kokand, Andijan and Namangan in Uzbekistan, Khudjand in Tajikistan and Osh in Kyrgyzstan.

The Fergana Valley surface, in particular its central part, presents a terraced plain with multitude of debris cones. The location of the two meteorological stations that influence the experimental areas located in Uzbekistan ("Azizbek-1"), and Kyrgyzstan ("Sandik" and "Toloikon") are presented in Table 4.

Table 4. Location of the meteorological stations used for the Fergana experiments.

Meteorological station	Latitude	Longitude	Altitude	Anemometer height
Fergana (Uzbekistan)	40.77º N	71.09º E	439	2
Karasu (Kyrgyzstan)	40.3º N	72.48º E	888	10

The absolute temperature maximum occurs in July (up to +35ºC) and the absolute minimum in January (-14^{0}C). The precipitation ranges within 90-387 mm. The average monthly maximum and minimum temperatures and relative humidity, and average monthly precipitation and average monthly reference evapotranspiration for the Fergana meteorological station are shown in Fig. 5 and 6 referring to the period 1970-2003.

For the Karasu meteorological station the same meteorological variables are shown in Fig. 7 and 8 relative to the periods 1959-91 and 2001-03. The average and standard deviation of those climate variables are shown in Tables 5 and 6.

Analyzing Figs. 7 and 8 it can be concluded that the climatic variables have the same pattern exception made for the precipitation, that is much higher by April and December in the period 2001-03 than for the average (Fig. 8).

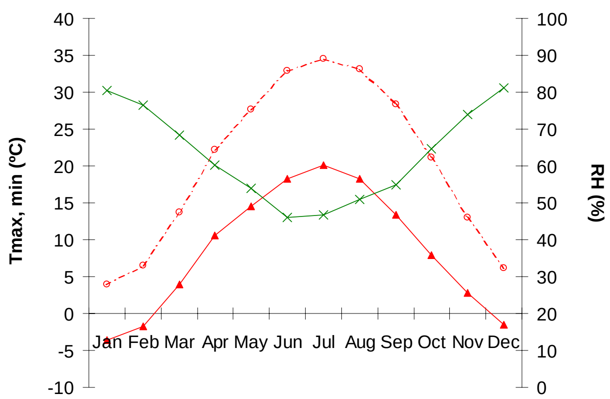


Fig. 5. Average monthly minimum ―▲― and maximum - · ⊖ · - temperature, and relative humidity ―✕― at Fergana meteorological station, (1970-2003).

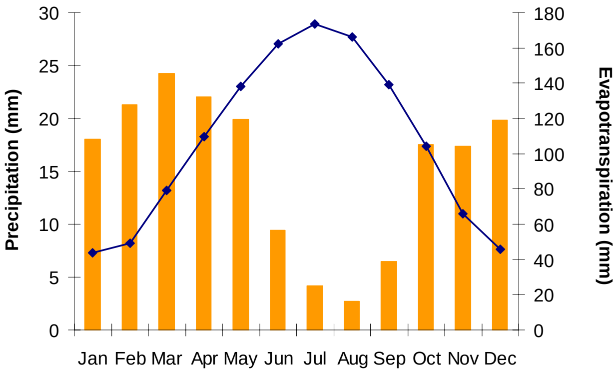
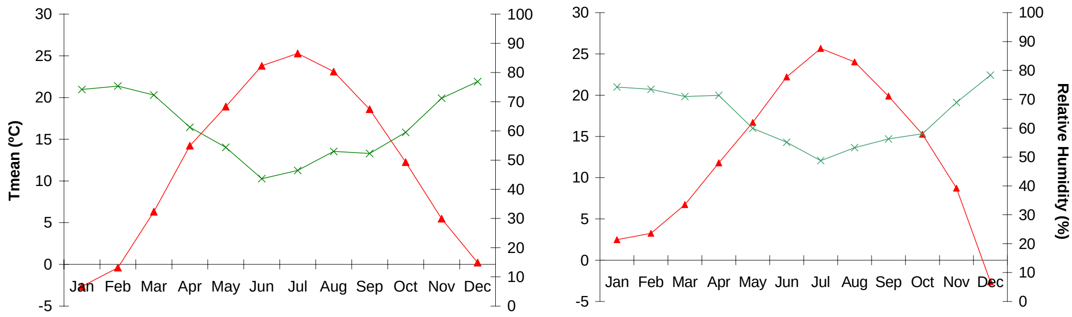
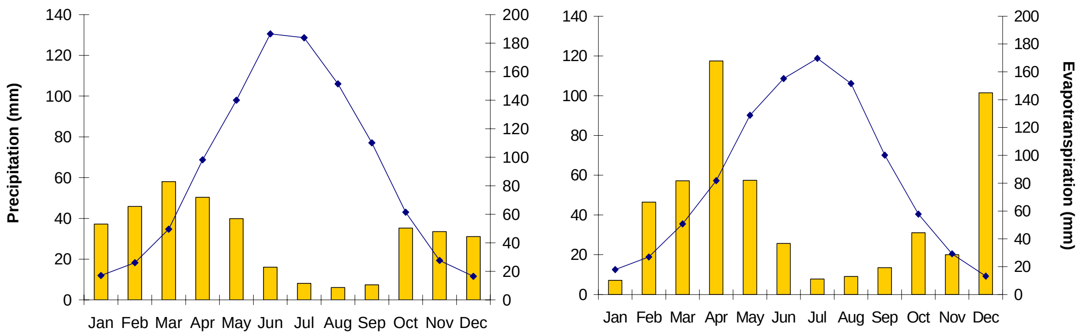


Fig. 6. Average monthly precipitation ( ) and average monthly reference evapotranspiration (ETo) ( ) at Fergana meteorological station (1970-2003).



1959-91 2001-03

Fig. 7. Average monthly mean ( ) temperature, and relative humidity ( ) at Karasu meteorological station.



1959-91 2001-03

Fig. 8. Average monthly precipitation ( ) and average monthly reference evapotranspiration (ETo) ( ) at Karasu meteorological station.

Table 5. Average ($\bar{X}$) and standard deviation (s) of the meteorological data series of the Fergana meteorological station (1970-2003).

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T_{min}	$\bar{X}$	-3.7	-1.7	4.0	10.6	14.5	18.3	20.1	18.2	13.3	7.9	2.8	-1.5
[ºC]	*s*	*3.1*	*3.9*	*2.9*	*2.3*	*2.0*	*1.6*	*1.3*	*1.7*	*1.9*	*2.4*	*2.8*	*3.1*
T_{max}	$\bar{X}$	4.0	6.6	13.7	22.3	27.7	32.9	34.6	33.1	28.4	21.2	13.1	6.2
[ºC]	*s*	*3.1*	*4.7*	*4.1*	*3.5*	*3.1*	*2.2*	*1.9*	*1.9*	*3.0*	*3.3*	*4.2*	*3.7*
RH	$\bar{X}$	81	77	68	60	54	46	47	51	55	65	74	81
[%]	*s*	*5.4*	*6.5*	*8.0*	*8.7*	*7.6*	*5.9*	*5.2*	*4.3*	*5.7*	*7.2*	*8.6*	*6.4*
u_z	$\bar{X}$	1.0	1.2	1.4	1.6	1.7	1.7	1.5	1.4	1.2	1.1	1.1	1.0
[m s^{-1}]	*s*	*0.3*	*0.3*	*0.3*	*0.4*	*0.7*	*0.5*	*0.4*	*0.3*	*0.3*	*0.3*	*0.3*	*0.4*
n	$\bar{X}$	3	4	5	7	9	11	11	11	9	7	5	3
[h]	*s*	*1.5*	*1.8*	*1.8*	*1.9*	*1.6*	*1.3*	*1.1*	*1.1*	*1.3*	*1.5*	*1.8*	*1.5*
ET_o	$\bar{X}$	1.4	1.7	2.5	3.7	4.5	5.5	5.7	5.4	4.7	3.4	2.2	1.5
[mm d^{-1}]	*s*	*0.3*	*0.4*	*0.6*	*0.7*	*0.7*	*0.7*	*0.6*	*0.4*	*0.5*	*0.5*	*0.5*	*0.3*
P	$\bar{X}$	18	21	24	22	20	9	4	3	6	18	17	20
[mm]	*s*	*12.2*	*17.2*	*12.8*	*19.2*	*16.6*	*9.4*	*3.8*	*3.6*	*7.8*	*28.4*	*17.3*	*15.5*

Table 6. Average ($\bar{X}$) and standard deviation (s) for the Karasu meteorological station (1959-91 and 2001-03).

			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T_{mean}	59-91	$\bar{X}$	-2.6	-0.4	6.3	14.2	18.9	23.8	25.3	23.1	18.6	12.3	5.5	0.2
[ºC]		s	*2. 7*	*3.5*	*1.9*	*1.4*	*1.4*	*1.1*	*1.1*	*0.9*	*0.8*	*1.4*	*2.0*	*2.6*
	01-03	$\bar{X}$	2.5	3.3	6.7	12.5	17.7	22.9	25.5	24.1	19.7	16.2	8.7	-2.6
		s	*1.9*	*1.8*	*5.1*	*4.4*	*4.2*	*2.6*	*2.0*	*2.1*	*2.7*	*3.6*	*3.8*	*4.2*
RH	59-91	$\bar{X}$	74	75	72	61	54	44	46	53	52	59	71	77
[%]		s	*4.6*	*4.3*	*6.8*	*8.2*	*7.4*	*6.2*	*6.2*	*5.6*	*5.4*	*7.9*	*8.5*	*6.1*
	01-03	$\bar{X}$	74	73	71	69	59	53	49	54	54	59	69	78
		s	*13.1*	*9.9*	*11.7*	*12.7*	*11.1*	*10.0*	*5.0*	*6.9*	*9.7*	*12.2*	*13.8*	*13.7*
ET_o	59-91	$\bar{X}$	1	1	2	3	5	6	6	5	4	2	1	1
[mm d^{-1}]		s	*0.1*	*0.2*	*0.3*	*0.5*	*0.5*	*0.5*	*0.5*	*0.3*	*0.3*	*0.3*	*0.2*	*0.1*
	01-03	$\bar{X}$	1	1	2	3	4	5	5	5	3	2	1	0
		s	*0.1*	*0.2*	*0.5*	*0.8*	*1.0*	*0.8*	*0.6*	*0.6*	*0.5*	*0.7*	*0.4*	*0.2*
P	59-91	$\bar{X}$	37	46	58	50	40	16	8	6	7	35	33	31
[mm]		s	*23.0*	*21.8*	*33.8*	*29.4*	*25.3*	*11.5*	*11.7*	*8.1*	*9.5*	*41.0*	*21.3*	*23.9*
	01-03	$\bar{X}$	7	47	57	117	57	26	8	9	14	31	20	102
		s	*0.5*	*3.2*	*4.7*	*28.2*	*14.7*	*10.1*	*2.3*	*3.5*	*7.0*	*3.7*	*2.0*	*4.4*

The main soils in Fergana Valley are loamy and clay-loam. For each location, soil hydraulic proprieties were determined (Table 7). These data were obtained from an appropriate survey and using laboratory methods for the full range of soil water tension. The soil depth varies in the area, from 1 to 1.5 m.

Table 7. Soil hydraulic proprieties relative to the total available soil water (TAW) for the experimental areas in Fergana Valley.

Location		Depth (m)	θ_{Fc} ($m^3\ m^{-3}$)	θ_{Wp} ($m^3\ m^{-3}$)	TAW (mm/m)
Azizbek farm	Cotton (field #13)	0-0.35	0.37	0.2	155
		0.35-0.50	0.32	0.19	
		0.50-0.76	0.35	0.19	
		0.76-1.30	0.35	0.2	
	Cotton (field #5)	0-1.10	0.30	0.09	210
	Winter wheat	0-1.50	0.33	0.08	250
Sandik farm		0-1.00	0.27	0.07	270
Toloikon farm		0-1.00	0.28	0.06	220

Observations of soil moisture were made between irrigation events, as well as before and after irrigations. The gravimetric method was used for the first 20 cm in all fields and the neutron probe for the remaining soil depths. For the "Azizbek-1" farm since the soil depth was of 130 cm with 4 layers the measurements were at 27.5, 42.5, 67.5 and 112.5 cm. For the cotton field in "Sandik" farm, observations were performed at 35, 50, 70 and 90 cm; the soil was 100 cm depth with consideration of only one homogeneous layer. In the winter wheat field of the "Toloikon" farm, the neutron probe observations were made at 25, 40, 60, 90 and 100 cm.

Due to the role that groundwater contribution plays in satisfying crop water requirements, studies performed in the "Azizbek-1" farm during the period 2001-03 included the observation of watertable depths, which varied 0.84-2.62 m. The water table depth was measured on a weekly basis and plant development was observed twice a month for each development stage. Following these observations, the equations used for the computation of the groundwater contribution and percolation (Eq. 2 to 7) are shown in Table 8.

Table 8. Summary of parameters to compute the capillary rise and percolation in Azizbek-1, Fergana.

Parameterized groundwater contribution equations		
$W_c = 360 \cdot D_w^{-0.172}$		
$W_s = 305 \cdot D_w^{-0.2705}$		
$D_{wc} = -1.3 \cdot ET_m + 6.6$	when	$ET_m \leq 4$ mm/d
$D_{wc} = 1.4$	when	$ET_m > 4$ mm/d
$G_{max} = k \cdot ET_m$	when	$D_w \leq D_{wc}$
$G_{max} = 4.597 \cdot D_w^{-0.6511}$	when	$D_w > D_{wc}$
$k = 1 - e^{-0.6 \cdot LAI}$	when	$ET_m \leq 4$ mm/d
$k = 38/ETm$	when	$ET_m > 4$ mm/d
Parameterized percolation equation		
$W = 390 \cdot t^{-0.0173}$		

Taking into consideration the soil hydraulic properties of the "Azizbek-1" soils, the values considered for the groundwater contribution parameters listed in Table 8, for the Fergana location, are as follows: a_1 = 360; b_1 = -0.17; a_2 = 305; b_2 = -0.27; a_3 = -1.5; b_3 = 6.6; a_4 = 4.6; b_4 = -0.65. The parameters of the percolation equation (7) are a = 390 and b = -0.02 and it was considered that field capacity was attained 5 days after the heavy surface irrigation applications.

Model calibration for cotton in the Hunger Steppe

Reference Evapotranspiration

The monthly reference evapotranspiration computed with the FAO Penman Monteith method (Allen *et al*., 2001) using the EVAP56 model for the period 1984-86 (data were lost for the years 1982 and 1983) were compared with the GGI3000 evaporation pan for the cotton growth periods, April-September 1984-86 (Fig. 9). Results show that the pan coefficient is very close to 1.0 (0.99) but data is scattered around the regression line (R^2 = 0.69).

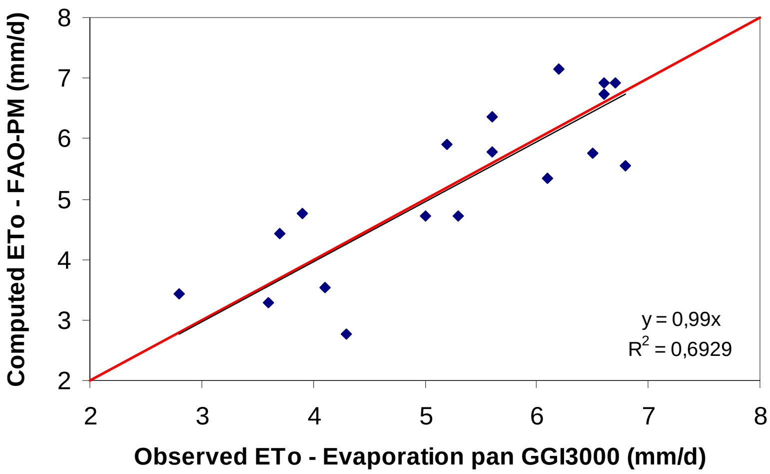


Fig. 9. Comparison among observed (GGI3000 pan) and computed (FAO-PM) monthly reference evapotranspiration for the Hunger steppe, 1984-86).

The potential evapotranspiration was formerly computed using the Ivanov method (Eq. 2). Results comparing both methods are given in Fig. 10. Results show a regression coefficient much above 1, thus great differences between methods formerly used. Causes for that could not be identified.

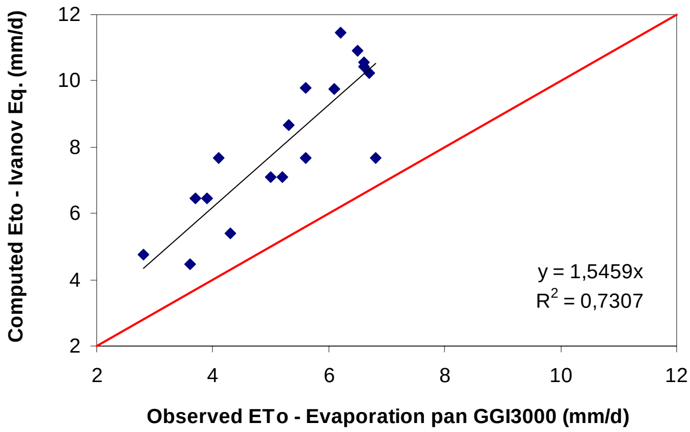


Fig. 10. Comparing observed GGI3000 pan evaporation with Ivanov potential evapotranspiration (monthly values, Hunger steppe, 1984-86).

Soil water content

For the calibration/validation of the ISAREG model to Central Asia conditions, field observations performed from 1983 to 1988 in the "Fergana" state farm, SyrDarya oblast, were used. Data utilized for the calibration refers to weather data for ETo computation as referred before, groundwater depths data to estimate the groundwater contribution, and soil moisture data to be compared with those simulated. The calibration consisted in searching the Kc and p values that lead to the best fitting of observed soil moisture. The irrigations depths corresponding to the experiments simulated are presented in Table 9. Results comparing the simulated with observed soil moisture for 1983 to 1987 are given in Fig 11.

Table 9. Irrigation scheduling and total irrigation depths (mm) used for the computation of the soil moisture, Hunger Steppe (1982-87).

Year	Dates	Irrigation after planting (mm)	Total irrigation depths (mm)
1982	1 Jul	260	520
	6 Aug	260	
1983	20 Jun	230	630
	22 Jul	200	
	27 Aug	200	
1984	18 Jun	161	630
	31 Jul	250	
	21 Aug	219	
1985	16 Jul	310	310
1986	3 Jun	62	432
	3 Jul	200	
	11 Aug	170	
1987	14 Jul	220	400
	30 Aug	180	

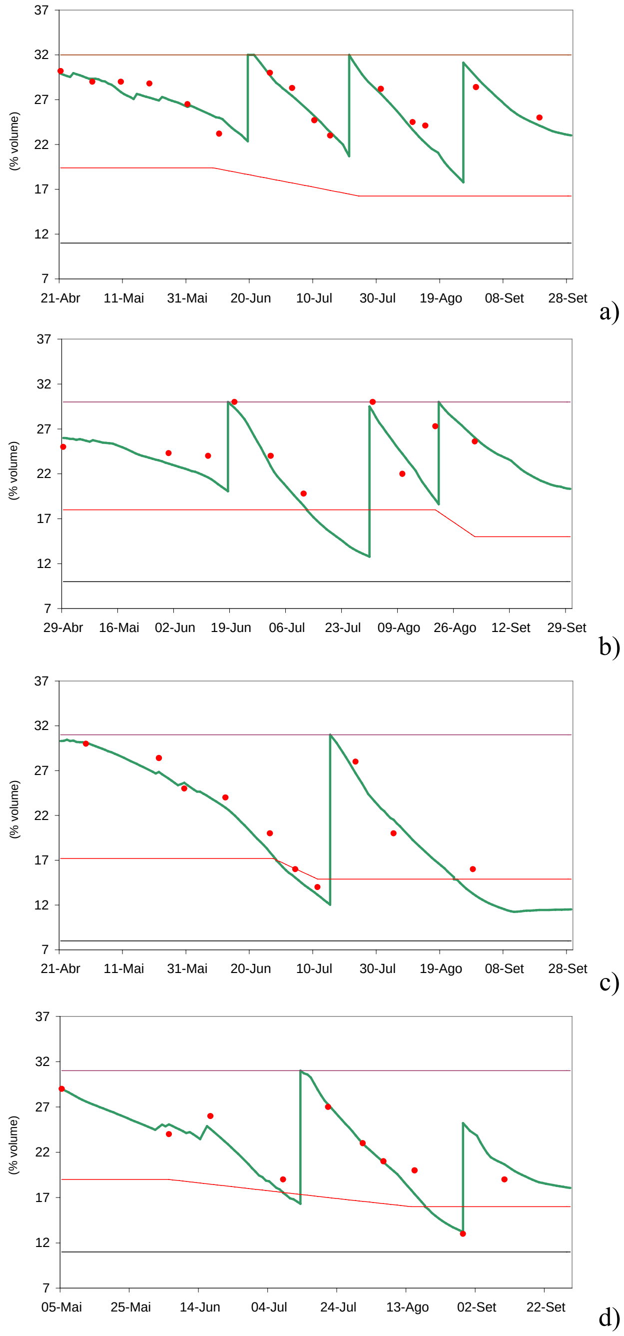


Fig. 11. Simulated (——) *vs.* observed (•) soil moisture for cotton, Hunger Steppe: a) 1983; b) 1984; c) 1985; and d) 1987.

The results show a good agreement for the period 1982-87; therefore indicating that the ISAREG model adequately predicts soil moisture during growing season in Hunger Steppe when the K_c and p curves described in Table 11 are adopted. In addition, the seasonal yield response factor, K_y = 0.85 was also adopted. A summary of the fitting of observed and simulated soil moisture is given in Fig. 12, which shows a regression coefficient close to 1.0 and a high coefficient of determination.

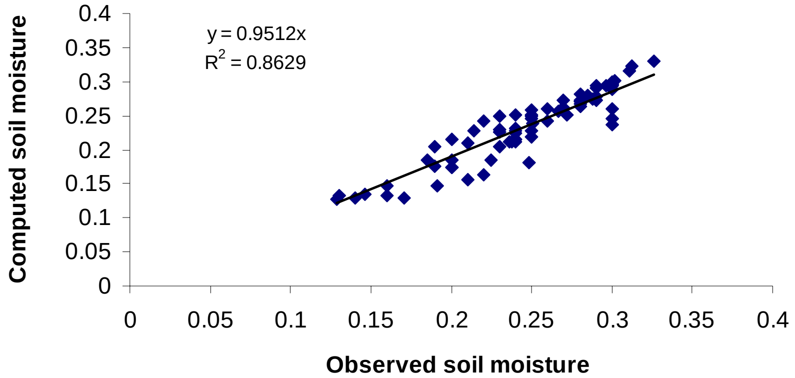


Fig. 12. Comparing observed and simulated soil moisture, Hunger Steppe, 1982-1987.

Crop evapotranspiration

In addition to comparing soil moisture, also the actual cotton ET values computed with ISAREG were compared with those observed with the energy balance method. A graphical comparison is presented in Fig. 13.

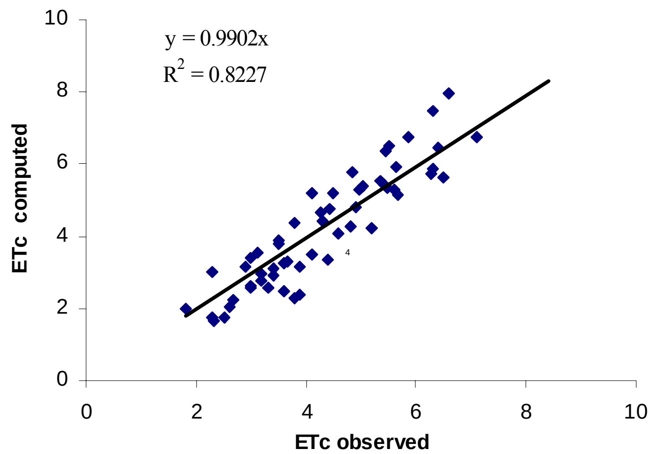


Fig. 13. Observed and computed crop evapotranspiration values (Hunger Steppe, 1982-1988).

Results in Fig. 13 show a very good agreement between simulated and observed values, with a regression coefficient very close to 1.0 and a high coefficient of determination.

Seasonal cotton evapotranspiration values observed and calculated with ISAREG for Hunger Steppe are presented in Table 10. Differences are generally small, ranging from 0.5 to 12%.

Table 10. Comparison of measured (energy balance balance method) and ISAREG calculated seasonal cotton evapotranspiration (Hunger Steppe, 1983-1987).

ET_{cot} (mm)	1983	1984	1985	1986	1987
Observed	730	670	685	721	701
ISAREG	678	755	694	748	688
Difference (%)	7	12	1	4	2

Table 11 shows the crop parameters relative to the above referred model testing.

Table 11. Calibrated cotton growth stages, crop coefficients (K_c) and depletion fractions for no stress (Hunger Steppe, 1982–1987).

Parameters	*Initial*	*Development*	*Mid season*	*End season*
1982				
Period length (dates)	1/04 –14/04	15/04 24/05	25/05 – 19/08	20/08 – 15/09
Crop coefficients, K_c	0.4	0.42-1.08	1.08	1.08-0.8
Depletion fraction, p	0.99	0.6	0.62	0.74
1983				
Period length (dates)	22/04 – 8/06	9/06 – 9/07	10/07 – 6/09	7/09 – 30/09
Crop coefficients, K_c	0.5	0.5-1	1	1-0.25
Depletion fraction, p	0.6	0.7	0.75	0.75
1984				
Period length (dates)	29/04 – 5/06	6/06 – 25/06	26/06 – 31/08	1/09 – 30/09
Crop coefficients, K_c	0.35	0.35-1.2	1.2	1.2-0.6
Depletion fraction, p	0.6	0.6	0.6	0.75
1985				
Period length (dates)	22/04 – 9/06	10/06 – 27/06	28/06 – 24/08	25/08 – 30/09
Crop coefficients, K_c	0.55	0.55-1.05	1.05	1.05-0.25
Depletion fraction, p	0.6	0.6	0.6	0.7
1986				
Period length (dates)	1/04 – 16/04	17/04 – 14/06	15/06 – 31/08	1/09 – 20/09
Crop coefficients, K_c	0.55	0.55-1.1	1.1	1.1-0.4
Depletion fraction, p	0.6	0.7	0.7	0.73
1987				
Period length (dates)	6/05 – 5/06	6/06 – 21/07	22/07 – 31/08	1/09 – 30/09
Crop coefficients, K_c	0.45	0.45-1.1	1.1	1.1-0.4
Depletion fraction, p	0.6	0.7	0.75	0.75

The $K_{c\ ini}$ are relatively high since a large irrigation before planting was always required. Instead, the $K_{c\ mid}$ are generally lower than those recommended by Allen *et al*. (2001) while $K_{c\ end}$ are in the range of those recommended by those authors. The depletion fractions p are generally higher than those proposed by Allen *et al*. (2001).

Model calibration for cotton and wheat in Fergana Valley

Reference evapotranspiration

The reference evapotranspiration ET_o was computed with the FAO-PM method using 10-day values for Fergana relative to the period 1970-2003 and daily values for the period 2001-03. For Karasu, Osh oblast, daily values were computed for the period 2001-03. To compute the reference evapotranspiration with the EVAP56 model in both locations, the climatic parameters used were: maximum and minimum temperatures (ºC), wind speed (m/s), actual sunshine duration (h) and mean relative humidity (%). In Fergana, data refers to the cotton growth period, i.e. from April to November. The results comparing ETo (FAO-PM) with observed GGI-3000 evaporation are shown in Fig. 14 and 15.

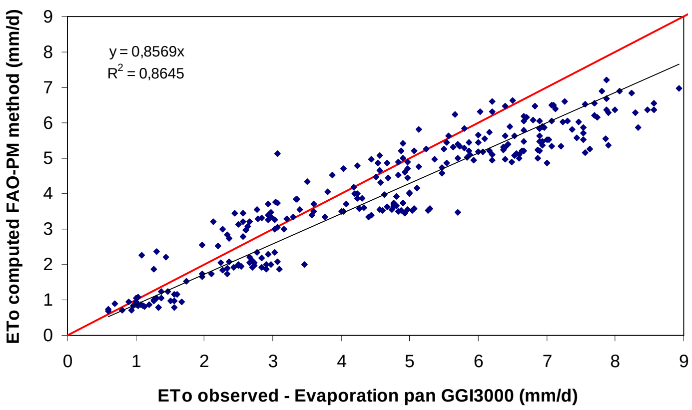


Fig. 14. Comparison between observed average 10-day GGI3000 pan evaporation and computed FAO-PM reference evapotranspiration (mm d^{-1}) for Fergana, 1970-2003.

By the observation of Fig. 14 and 15, it can be concluded that the observed GGI3000 pan evaporation values may be converted into FAO-PM reference evapotranspiration using a pan coefficient of 0.856 to 0.806.

The monthly FAO-PM reference evapotranspiration were also compared with ET computed with the Ivanov equation (Fig. 16). Converting the last into the FAO-PM ET requires a conversion coefficient equal to 0.70.

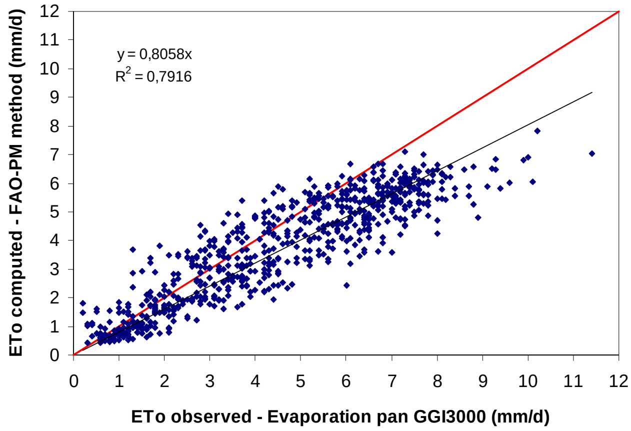


Fig. 15. Comparison between observed daily GGI3000 pan evaporation and computed daily FAO-PM reference evapotranspiration in Fergana oblast (2001-03).

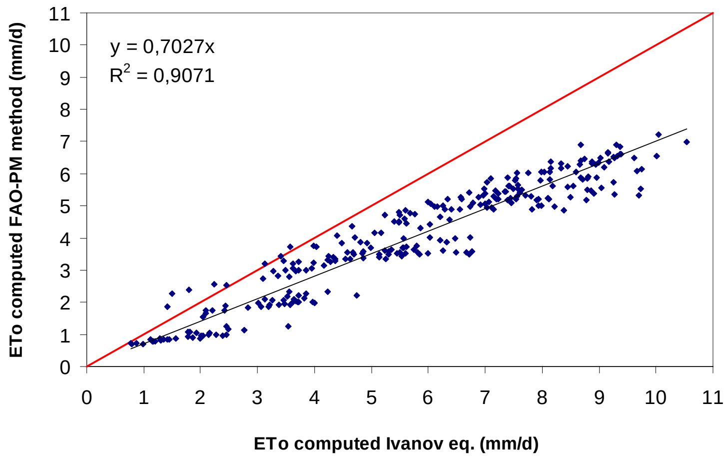


Fig. 16. Comparison between FAO-PM reference evapotranspiration and ET computed with Ivanov's formula for Fergana oblast for the period 1970-2003 (April-November).

In the Osh oblast the reference evapotranspiration was computed for the cotton and winter wheat growth periods, respectively September 2001 - August 2002 and April - October 2003. The comparison between observed GGI3000 pan evaporation and ETo (FAO-PM) is shown in Fig. 17. These results show that the pan coefficient is now 0.602, much lower than for Fergana, which may be a consequence of the site conditions.

The monthly FAO-PM reference evapotranspiration was also compared with Ivanov ETp (Fig. 18). Converting the last into the FAO-PM ET requires a transfer coefficient equal to 0.76, which is similar to that for Fergana.

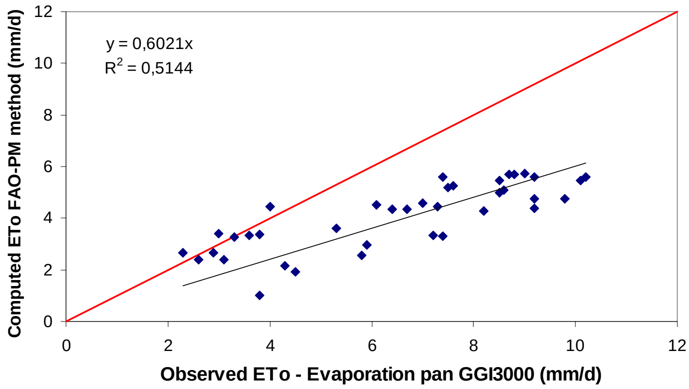


Fig. 17. Comparison between observed (evaporation pan GGI3000) and computed reference evapotranspiration (FAO-PM), for Osh oblast, 2001-03.

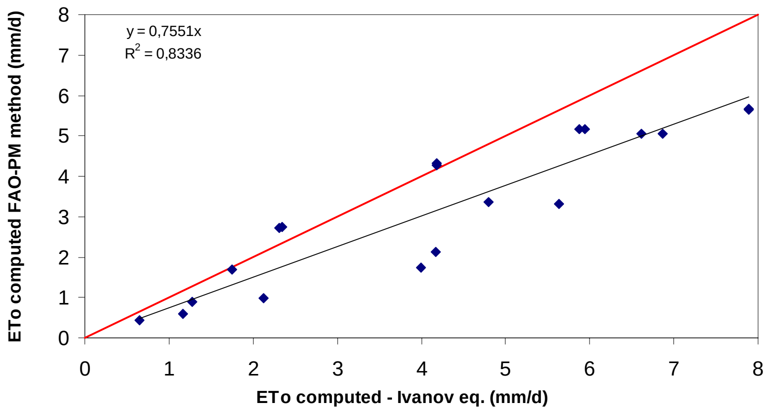


Fig. 18. Comparison between FAO-PM reference evapotranspiration and Ivanov's ET for Osh and the period 2001-03.

Cotton

The validation of the ISAREG model for cotton was made by comparing the simulated with the observed soil moisture content. The total irrigation depths used for each simulation correspond to the actual conditions (Table 12). Simulation results are presented in Fig. 19.

For the computation of cotton crop coefficients in Fergana oblast, the climatic data used referred to the period 2001-03; daily data was used. For the Osh oblast, daily climatic data for 2003 were used. The computed values are shown in Table 13.

Table 12. Irrigation scheduling and total irrigation depths.

Experimental farm	Dates	Irrigation depths (mm)	Total (mm)
Azizbek (field #13)	8 Jun	119	865
	4 Jul	202	
	17 Jul	113	
	30 Jul	155	
	14 Aug	183	
	16 Sep	93	
Azizbek (field #5)	2 Jun	127	621
	25 Jun	174	
	11 Jul	123	
	25 Jul	111	
	7 Aug	86	
Sandik	24 Jun	177	427
	13 Jul	78	
	27 Jul	58	
	9 Aug	14	
	12 Aug	100	

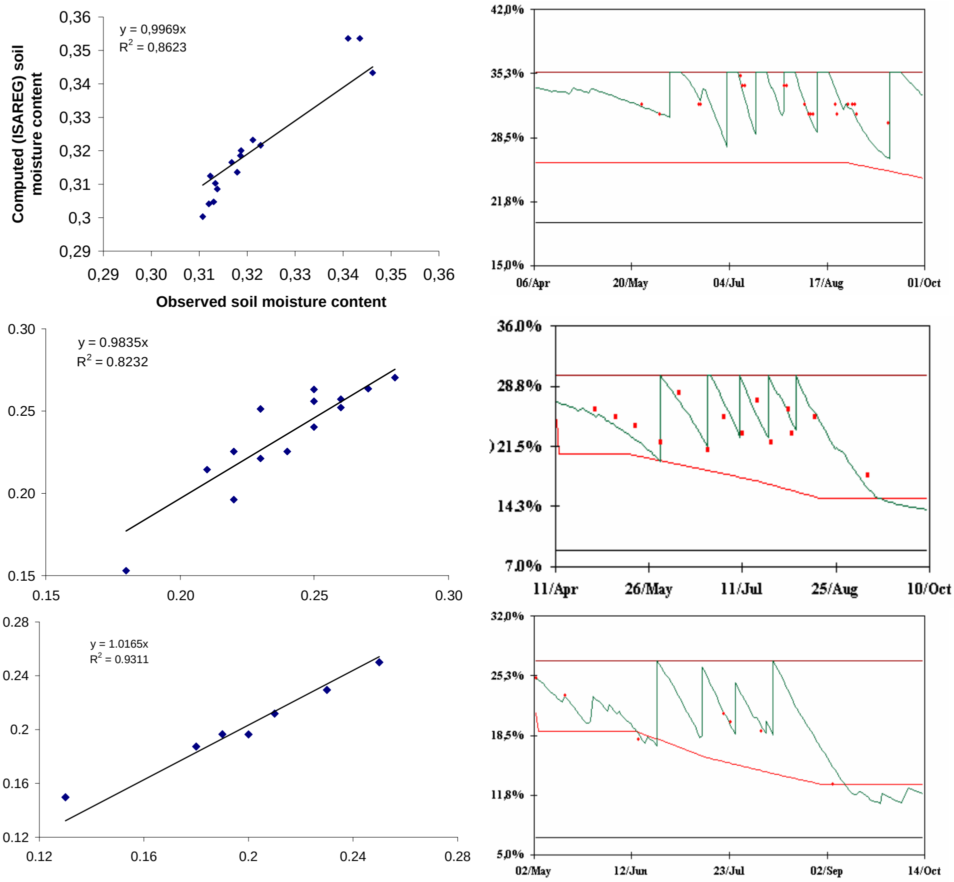


Fig. 19. Comparison between observed and simulated soil water content for cotton: a) and b) at the "Azizbek-1", 2001 (field #13 and 5); and c) at "Sandik" farm, 2003.

In the computation of the soil moisture using the ISAREG model it was considered the referred above reference evapotranspiration, crop parameters as indicated in Table 13, the actual irrigation schedule and the groundwater contribution.

Table 13. Crop growth stages, crop coefficients (K_c), root length (Z_r), depletion fractions for no stress (p), and yield response factor (K_y) for cotton in Fergana Valley.

Azizbek-1 farm (Fergana oblast)				
Field #13				
	Initial	*Development*	*Mid season*	*End season*
Period lengths (dates)	8/04 – 7/06	8/06 – 4/07	5/07 – 27/08	28/08 – 1/10
K_c	0.11	0.11 – 1.0	1.0	1.0 - 0.55
Z_r [m]	0.7	0.7	0.7	0.7
p	0.6	0.6	0.6	0.7
K_y	0.85			
Field #5				
Period lengths (dates)	13/04 – 17/05	18/05 – 17/07	18/07 – 31/08	1/09 – 10/10
K_c	0.35	0.35-1.15	1.15	0.6
Z_r [m]	1.1	1.1	1.1	1.1
p	0.25	0.45-0.6	0.7	0.7
K_y	0.85			
Sandik farm (Osh oblast)				
Period lengths (dates)	4/05 – 14/06	15/06 – 14/07	15/07 – 30/08	1/09 -14/10
K_c	0.67	0.67-1	1	0.65
Z_r [m]	1	1	1	1
p	0.4	0.55	0.65	0.7
K_y	0.85			

The computed and observed soil moisture showed for all studied cases a good agreement, with the regression coefficient close to 1.0 and the coefficient of determination near 0.9. Thus, the model adequately simulates the soil moisture for the irrigated cotton crop.

Winter wheat

The validation of the ISAREG model was made by comparing the simulated soil moisture content with the observed values (Fig. 20). The total irrigation depths, representing the actual conditions, used for each case presented in Fig. 20 were 265 and 548 mm respectively. The computed and observed soil moisture showed for both studied cases a good agreement, with the regression coefficient close to 1.0 and the coefficient of determination near 0.9. Thus, the model adequately simulates the soil moisture for the irrigated cotton crop.

For the computation of winter wheat crop coefficients in Fergana and Osh oblasts the daily climatic data used referred to the period 2001-02. The calibrated crop parameterss are shown in Table 14.

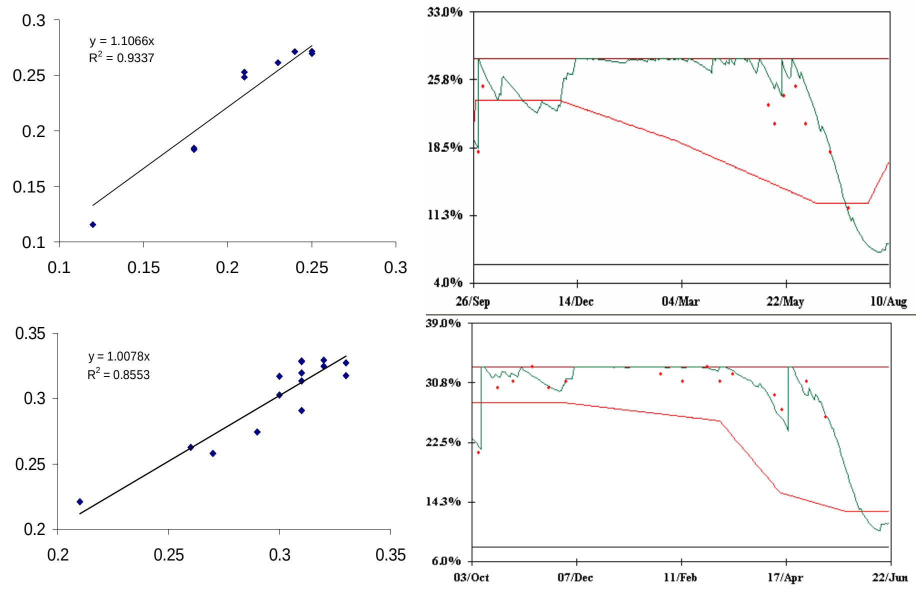


Fig. 20. Comparison between observed and simulated soil water content for winter wheat at “Toloikon” farm, 2001-02 (above) and at “Azizbek-1” farm 2001-02 (below).

Table 14. Crop growth stages, crop coefficients (Kc), root length (Zr), depletion fractions for no stress (p), and yield response factor (K_y) for the winter wheat crop in the Fergana Valley.

	Planting	Frozen soil	Development	Mid season	End
Azizbek-1 Farm (Fergana oblast)					
Period lengths	5/10–30/11	1/12– 7/03	08/03–14/04	15/04–25/05	26/05–22/06
K_c	1.14	0.2	1.20	1.20	0.35
Z_r [m]	0.7	0.7	0.7	0.7	0.7
p	0.2	0.2	0.3	0.7	0.8
K_y			1.0		
Toloikon farm (Osh oblast)					
Period lengths	28/09–30/11	1/12– 8/02	1/03–14/06	15/06–24/07	25/07–10/08
K_c	0.9	0.4	0.9	1.1	0.5
Z_r [m]	1.5	1.5	1.5	1.5	1.5
p	0.3	0.2	0.4	0.7	0.5
K_y			0.9		

Groundwater contribution

Data in Fig. 21 shows that groundwater contribution in Azizbek-1 farm, Fergana, is not negligible when crop ET is high and the groundwater depth is low due to irrigation in the surrounding fields. This applies to both cotton and wheat crops.

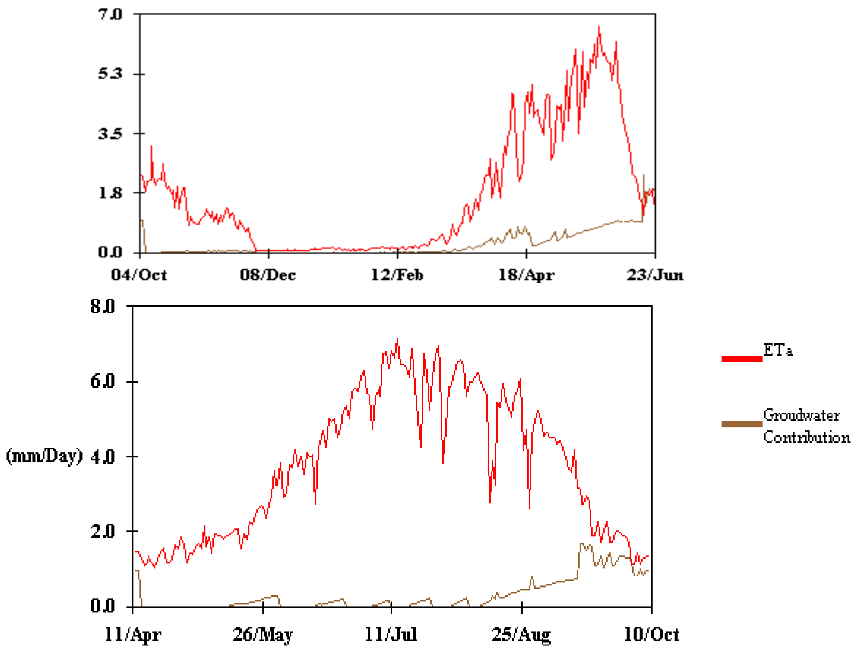


Fig. 21. Actual evapotranspiration and groundwater contribution (mm/day) during the growing seasons of: a) winter wheat (2001-2002) and b) cotton (2001), Azizbek farm.

Conclusions

The study above shows that using the former methods for estimating the reference ET – the GGI 3000 pan evaporation and the Ivanov ETp – makes it possible to have relatively large variations from a site to another. The coefficients relating these two estimation methods and them with the ETo computed with the FAO-PM method are different in Fergana and in the Hunger Steppe. To adopt common crop coefficients requires that variations in ETo are only dependent from the climate and not from the station sitting. Therefore, the use of the FAO-PM equation (Allen *et al*., 1998) is recommendeded.

The calibration/validation of the ISAREG model was successfully performed against using former observations of the soil water and cotton ET at Syrdarya oblast, Hunger Steppe, for the period 1982 – 1988. For both the soil water and crop ET the regression coefficients relating simulated and observed values were close to 1.0 and the determination coefficients were larger than 0.9. Moreover, these results were obtained using specific parameters for the parametric equations used in ISAREG to compute groundwater contribution and percolation; thus, the good agreements obtained show that these parametric equations were appropriate to estimate the fluxes through the bottom of the root zone. The studies produced therefore good estimates of the crop coefficients and depletion fraction for no stress that may be used further in searching water saving irrigation schedules as in the companion paper (Cholpankulov *et al*., 2005).

The model was also tested for cotton and winter wheat in two locations of the Fergana Valley by comparing simulated against observed soil moisture. In case of the Fergana oblast site, also the groundwater contribution and percolation equations were parameterized and tested. Results from comparing the model simulated soil moisture with observations using a regression through the origin produced regression coefficients close to 1.0 and determination coefficients close to 0.9. Thus, a good agreement obtained shows that the model was successfully tested and the derived crop parameters can be used for searching appropriate irrigation schedules for the area.

Acknowledgements

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