WP: 3 Climatological monitoring and mapping system
Activity: 3.2.3 Development of irrigation scheduling system
Outputs: • **Irrigation scenarios for water saving and environmentally oriented sustainable agriculture in partner countries** • **Net irrigation requirements (NIR) and irrigation demand probability curves, yield decrease related to water saving for a series with at least 10 years**
Country: Bulgaria
Responsible (Name, email address, phone number): [redacted]
Contact person (Name, email address, phone number): [redacted]
Scientific staff (number, names):6 - [redacted]

Report on irrigation scheduling tools – case study for Bulgaria

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1 INTRODUCTION – BACKGROUND OF THE PROBLEM

The climate conditions in all agricultural regions of Bulgaria determine the variability of crop irrigation requirements over the years (Sabeva et al., 1968; Zahariev et al., 1986). Varlev et al. (2004), Petkov (2003), Varlev (2010) point out that irrigation is undoubtedly the main factor and the most effective management practice to mitigate or prevent the water stress effects of droughts on agricultural crops and to guarantee stable crop production during different climatic years. More over 170 large and 2000 small dams were built in Bulgaria in the period 1960-1980. Their dam capacity is over 5 mlrd. m^3 (Varlev, 2010; Petkov, 2003). About 6-8 mln.da used to be irrigated in Bulgaria in the 1980s. Hardly 0.35 mln.da, or 5% of the fit areas, are irrigated over the last 20 years (Petkov, 2003; Varlev, 2010). Furrow irrigation has been a wide–spread irrigation method in Bulgaria. It used to be applied over 70% of the irrigated area in this country, i.e. on 0.56 mil. ha in the 1980s.

The restoration of irrigation systems, the development and application of systems for estimation and early warning for irrigation needs and optimal irrigation scheduling, the application of water saving, energy-saving and environment friendly (adapted to soils characteristics) technologies and techniques of irrigation are outlined as measures in the framework of the National Action Program (NAP) 2007 - 2013 for sustainable land management and combat desertification (SLMCD).

Various studies have been carried out in Bulgaria to develop improved irrigation scheduling considering impacts on yields and water saving issues (Banov, 1988; Furdjev et al., 1994; Varlev et al., 1989, 1994; Varlev and Popova, 1999, Petrova, 2010). Long-term experiments were conducted in Thrace plain with the objective of recognizing the water relations of maize under deficit and full irrigation, as well as rainfed conditions (Eneva, 1993 & 1997). These data was later analysed with the water balance simulation model ISAREG, which was then calibrated and validated for different maize hybrids cropped in vertisols, chromic cambisols, luvisols and alluvial soil of the Thrace plain and Sofia field (Popova et al., 2006b; Popova, 2008; Popova and Pereira, 2008; 2009; 2010; Ivanova and Popova, 2011). The **ISAREG** model (Pereira et al., 2003) is a simulation tool for computing the soil water balance, generating alternative irrigation schedules and evaluating the respective impacts on crop yields.

Well calibrated water balance models are practical, precise and efficient tools to compute irrigation requirements and estimate their probabilities, to support irrigation management practices and to evaluate water stress impacts on yields. Such models are useful for scenario analyses aiming at optimal water saving and environmentally oriented irrigation practices for efficient water use in agriculture (Popova, 2008).

The reort consists of four chapters and conclusions. Chapter 2 involves description of five experimental sites of contrastive hydrological properties of soils located in South Bulgaria, input data for irrigation scheduling, irrigation alternatives applied using the simulation model ISAREG. In Chapter 3 are summarized results of calibration and validation of maize irrigation scheduling in the studied sites. In our previous studies the ISAREG model used to be validated using independent datasets relative to long-term experiments with maize hybrids of different resistance to water stress (Popova et al.2005, 2006, 2007; Popova 2008; Popova, Pereira 2010; Popova and Pereira 2011; Ivanova and Popova, 2011). The calibration consisted in deriving crop coefficients (Kc), that represent the ratio between crop and reference evapotranspiration, depletion fractions for no stress (p), i.e., the soil water fraction that may be extracted by the crop without causing water stress, and the yield response factors (Ky), which relate relative yield decreases due to water management with the relative evapotranspiration deficits. The validation proved that the ISAREG model and the calibrated parameters could be further used to generate and select irrigation scheduling alternatives for maize in the study area.

The Chapter 4 includes assessments of the impact of climate uncertainties on irrigation requirements for two of the explored maize hybrids in the studied sites using 36 years data series, 1970-2005 and several irrigation scheduling alternatives. Numerical simulation modeling exploring the validated ISAREG model and data from furrow irrigation experiments are used to define the irrigation scheduling strategies aimed at improved water use and water saving practices in the region. Climate uncertainties were simulated by considering two precipitation scenarios for the period 2005-2030, which were built from precipitation data relative to 1970-2005 referring to the maize irrigation season (July and August) (Popova, 2008; Popova and Pereira 2008; Popova 2010).

2 MATERIALS AND METHODS

2.1 Site description

Our study is carried out in five experimental sites (Fig. 1, Table 1) of contrastive hydrological properties of the soil, located in: Sofia field – Bozhurishte and Chelopechene; Thracian lowland – Tsalapitsa, Plovdiv region; Pastren and Zora, region of Stara Zagora. These fields are representative of some of the driest, warmest (Plovdiv and Stara Zagora, Thracian lowland) (Fig. 2a, b) and the coolest and wettest (Sofia field) agricultural areas of the country (Fig 2c).

Table 1. Location and soil types of the studies sites

Site	Lat	Ln	Alt., m	Soil type	Total available water capacity (TAW, mm m^{-1})
Bozhurishte	42°15’	23°45’	555	Vertisol	high (180)
Chelopechene	42°44’	23°28’	532	Chromic Luvisol	small (106)
Tsalapitsa	42°10’	24 °13’	180	Alluvial soil	small (116)
Pastren	42°16’	25°39’	150	Vertisol	high (173)
Zora	42°25’	25°39’	169	Chromic Cambisol	moderate (136)

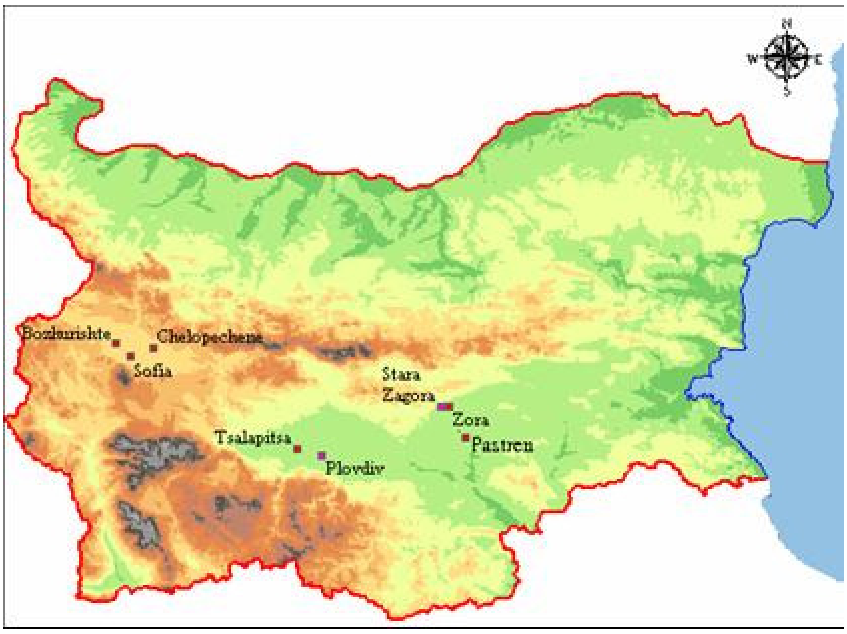
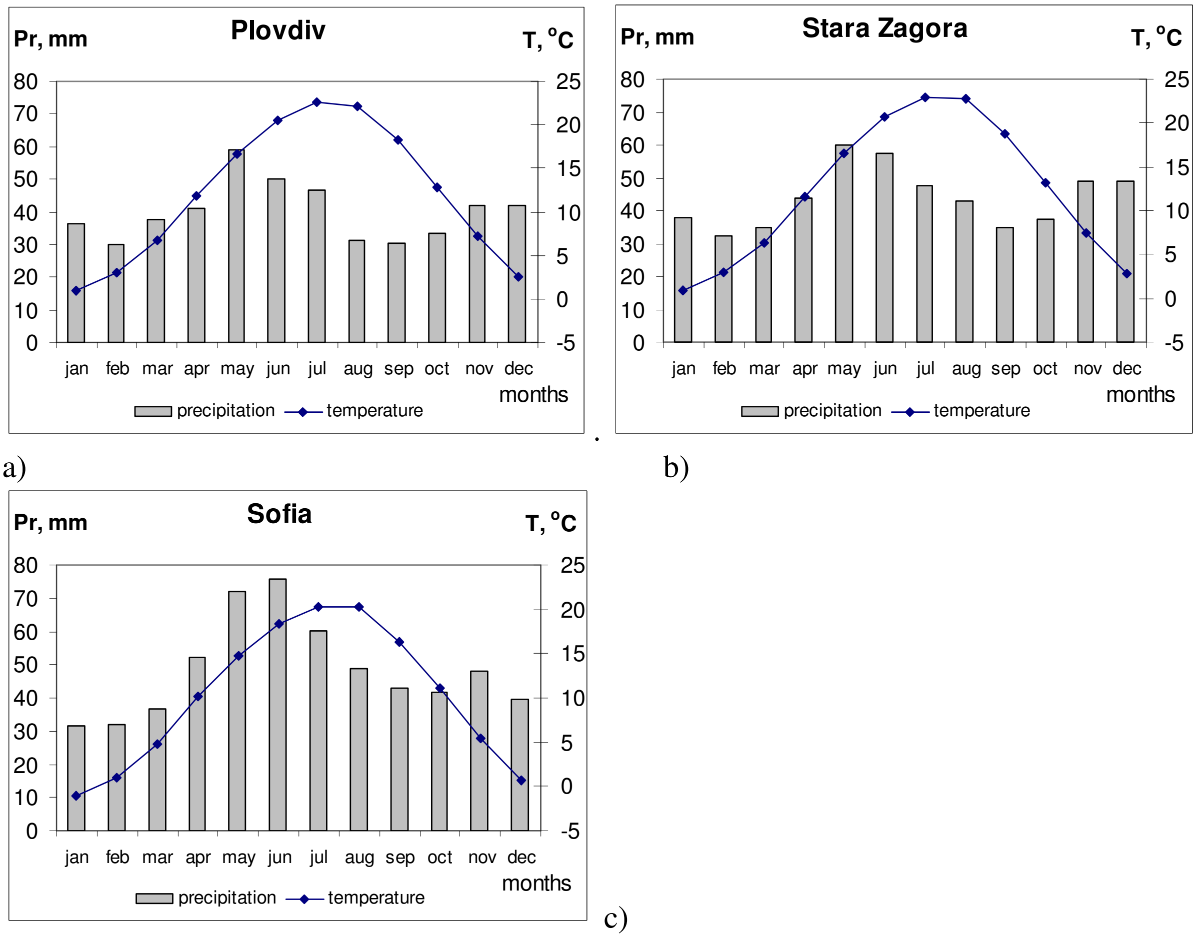


Figure 1. Location of experimental fields in the region of Sofia field and Thracian lowland.



a)

b)

c)

Figure 2. Mean monthly air temperature and precipitation of the studied sites over the period 1951-2004.

Maize is chozen as a test crop in this study because of its high economical importance for the country (ordered on the second place in the economy after wheat) and because of its high water sensitivity. About 1/3 of the areas cultivated with maize till the end of 1980s need irrigation. Detoriation of irrigation systems is one of the reasons for decreasing the mazie grown areas (Figure 3).

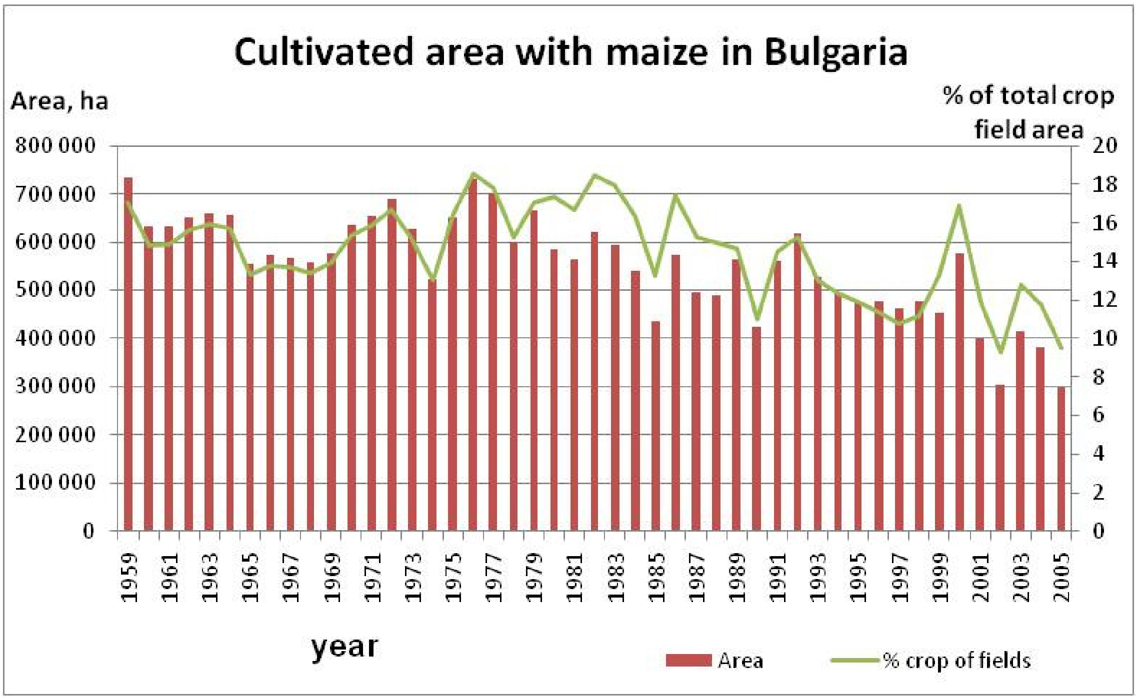


Figure 3. . Cultivated area with maize in Bulgaria.

2.2 *Input data for WinISAREG model*

Data required to perform the soil water balance with ISAREG are: (1) Weather data on precipitation and reference evapotranspiration (*ETo*); (2) Soil data referring to a multi-layered soil including, for each layer, the respective depth, field capacity and wilting point; (3) Crop data relative to the crop development stages and corresponding dates, crop coefficients, root depths and the soil water depletion fractions for no stress. The later version of the model adopts the updated methodology to compute crop evapotranspiration and irrigation requirements. Two auxiliary programs are used, one to compute *ETo*, including alternative methods when some weather variables are missing, the other to support crop parameterization. Yield impacts of water stress are assessed with the Stewart one-phase model when the yield response factor *Ky* is known. Simulation options include: (a) an irrigation schedule aiming at maximum yields; (b) an irrigation schedule using selected irrigation thresholds, including constant or variable irrigation depths; (c) an irrigation schedule when water is applied at given dates; (d) to evaluate water balance without irrigation, and (e) to compute the net crop water requirements for irrigation.

2.2.1 Soil characteristics and soil water measurements

The soil in Chelopechene (Fig. 1) is a chromic luvisol constituted of 42-43% clay and 30-33% sand in the top 70 cm. Clay is 24% respectively in the bottom layed where sand reaches 61% (Table 2). Water holding capacity of the soil profile is small (TAW=106 mm m^{-1}) (Table 1). The soil in Bojurishte site is a vertisol with one of the highest total available water (TAW) in Bulgaria (180 mm m^{-1}). Clay is 54 % in the top layer and 63 % in A_2B_1 horizon (Table 2).

Table 2. Main soil physical and hydraulic properties, Chelopechene and Bojurishte sites, Sofia.

Experimental site (soil type)	Horizon	Depth, cm	Particle size distribution, % (FAO, 1990)			Particles size distribution, %, (Kachinski, 1958)		Ksat
			Clay <0.002 mm	Silt 0.002-0.05 mm	Sand 0.05-2.0 mm	Physical clay <0.01 mm	Clay <0.001 mm	cm/day
Bojurishte	A_1	0-45	54	33	13	70.0	53.1	0.63
(Vertisol)	A_2B_1	45-100	63	27	10	73.8	58.2	0.63
	A_1l	0-28	32	32	36	43.5	11.3	93.3
Chelopechene	B_1t	33-45	43	27	30	54.7	38.1	15.9
(Cromic	B_2t	61-71	42	25	33			20.2
Luvisol)	Ck	95-130	24	15	61	40.5	28.3	39.9

The soil in Pustren site (Fig. 1) is a vertisol with high total available water (TAW) (173 mm m^{-1}) (Table 1). It is mainly constituted of clay, which is about 54-58% in the top layers (0-50 cm) and nearly 65% in the lower horizons (50-130 cm) (Table 3). The content of coarse sand is only 11% and 6% respectively. The soil in Zora is a chromic cambisol with a moderate TAW (136 mm m^{-1}). It is constituted of about 35-38% clay in the top layers (0-28 cm and 40-70 cm) and 21-26% in the lower horizons (71-130 cm). The content of coarse sand is only 32-40% and 49-56% respectively.

Table 3. Main soil physical and hydraulic properties, Pustren and Zora sites, Stara Zagora.

Experimental site (soil type)	Horizon	Depth	Particle size distribution, % (FAO, 1990)			Particle size distribution mm, % (Kachinskii, 1958)		K_{sat}	θ_{FC}	θ_{WP}
		(cm)	Clay <0.002 mm	Silt 0.002-0.05 mm	Sand 0.05-2.00 mm	Phys. clay <0.01 mm	Clay <0.001 mm	(cm day^{-1})	(cm^3 cm^{-3})	
Pustren (Vertisol)	A_1	0-26	53.5	33.7	12.8	62.1	45.5	7.9	0.42	0.27
	A_2	26-50	58.0	32.0	10.0	66.8	47.4	3.3	0.47	0.30
	A_3B_1	50-80	60.3	27.7	12.0	67.5	54.6	0.8	0.45	0.31
	B_2Cк	80-130	66.0	28.1	5.9	75.4	59.0	1.1	0.43	0.30

Zora (Chromic Cambisol)	A_1	0-28	35.0	32.3	32.4	52.7	18.9	33.0	0.33	0.17
	A_2	28-40	21.0	39.6	39.4	53.3	18.3	25.9	0.33	0.18
	A_3B_1	40-55	38.0	28.8	33.2	46.6	14.2	-	0.32	0.19
	B_2	55-71	38.0	25.1	36.9	45.1	14.2		0.31	0.19
	B_3	71-97	26.0	24.7	49.3	40.4	10.7		0.31	0.19
	C_1к	97-135	21.0	23.0	56.0	23.9	7.7	-	0.32	0.19

The physical and hydraulic properties of the alluvial soil in Tsalapitsa experimental station are shown in Table 4.

Table 4 Main soil physical and hydraulic properties of the alluvial soil at Tsalapitsa experimental site.

Depth,	Bulk density	Texture	Particle size distribution, %			Hydraulic conductivity at saturation (K_s), cm d^{-1}	Soil water, cm^3 cm^{-3}	
cm	g cm^{-3}		Clay	Silt	Sand		Field capacity	Wilting point
0-30	1.64	SL	9.3	23.1	67.6	62.2	0.26	0.08
30-60	1.60	SL	13.0	22.1	64.9	82.3	0.22	0.10
60-100	1.50	SCL	22.3	24.7	53.0	10.3	0.27	0.20
100-150	1.60	SL	17.0	23.1	53.9	62.2	0.24	0.14

The soil is constituted mainly of sand (53 to 68%). It has a sandy-loam texture over the upper two and the bottom layers, and a sandy-clay-loam texture from 60 to 100 cm depth.

The soil hydraulic properties were obtained from field measurements in a soil monolith under free drainage after saturation and from laboratory methods, which were used to derive the water retention curve and the hydraulic conductivity at saturation, Data in Table 4 indicate that the total available soil water is TAW = 116 mm m^{-1}. The hydraulic conductivity at saturation, K_s, ranges 10-82 cm day^{-1}. Soil moisture at field capacity (FC) and the wilting point (WP) were used as input to the ISAREG model.

The soil water content and matric potential in the experimental sites were observed not less than twice a week during the maize vegetation season using five different methods: gravimetric (sampling at each 10 cm down to 1.3 m), TDR and neutron probe (each 20 cm down to 1.3 m), electrical resistance gypsum blocks (as for neutron probe), and tensiometers (located at 40, 70, 1.00 and 1.30 m depth). These data allowed the accurate computation of the soil water balance including the estimation of deep percolation.

2.2.2 Meteorological data sets

The study includes different sets of daily data on precipitation (Pr), maximum and minimum air temperature (Tmax, Tmin), relative humidity (RH), wind speed (WS), and solar radiation (SH- sun shine duration) for model calibration and validation purposes depending on the availability of field experiemnetal data and climate characteristics of the year/period and computational task (Table 5).

Table 5. Meteorological data sets used for different computational tasks.

Site	Period (climate conditions)	ETo – validation with limited data sets	Maize hybrid	Year	Computational task	output
Stara Zagora	1976	Table 6, 7				
Pustren	1972-1980 (wet)		Kn-2L-611	1976	Calibration SM (fig. 6, 11a; table 9); Validation seasonal ETa (Table10; fig. 8a)	Kc, p (fig.5, table 8); Ky (table 11, Fig. 9a)
	1981-1992 (dry)		H708	1987	Validation SM (fig. 7b); seasonal ETa (Table10; fig. 8a)	Ky (table 11, Fig. 9b)
	1972-1992				Test of seasonal ETa (Table10; fig. 8a)	
Zora	1972-1977		Kn-2L-611	1976	Validation (Table 8); Test of seasonal ETa (Table10; fig. 8b)	
	1983-1985		H708		Test of seasonal ETa (Table10; fig. 8b)	
	1972-1990					NIR (fig. 17)
Tsalapitsa	1984-1991	Fig.4 , table 6, 7	H708	1988	Calibration SM (fig. 10a,b; 11a); validation (fig.10c-f, 13b); ETa (fig. 12, table 14);	Kc, p (table 12)
	1984-1991				Validation ETa (fig. 13, Table 14); Test YD)	
Plovdiv NIMH	1980-1984	Table 4, 5				
Bozhurishte	2003-2005		Kn509		Fig. 16, table 15, 16	Kc, p (table 6, 16); NIR (fig.17)
Celopechene						NIR (fig. 17)

2.2.2.1 Reference evapotranspiration

For computing the soil water balance a main input variable is reference evapotranspiration (ETo), which is estimated with the FAO Penman-Monteith method proposed by Allen et al. (1998) equation 1.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{900}{T+273} u_2 \,(e_s - e_a)}{\Delta + \gamma(1+0.34u_2)} \qquad (1)$$

where: R_n – net radiation at the crop surface [MJ m^{-2} day^{-1}]; G – soil heat flux density[MJ m^{-2} day^{-1}]; T – mean daily air temperature at 2 m height [^{o}C]; u_2 – wind speed at 2 m [m s^{-1}]; e_S – saturation vapor pressure [kPa]; e_a – actual vapor pressure [kPa]; e_s - e_a - saturation vapor pressure deficit [kPa]; Δ - slope vapor pressure curve [kPa.$^{o}C^{-1}$]; γ - psychrometric constant [kPa.$^{o}C^{-1}$].

The daily reference evapotranspiration ETo was computed with the Penman-Monteith equation (ETo-PM) using the FAO methodology for estimation of missing data (Allen et al., 1988) wich was previously tested for the Thrace plain (Popova et. Al, 2006) and Sofia field (Ivanova, Popova, 2010). The procedures to estimate the missing radiation data refer to the use of the maximum and the minimum daily temperature differences (eq.2) and data from a neighbour station. These studies have demonstrated that estimating solar radiation from maximum and minimum daily temperatures, eq. 2, allow to estimate ETo, with small standard errors of estimates, ranging from 0.17 to 0.22 mm day^{-1}. The recommended value of K_{Rs} coefficient is K_{Rs} =0.16 for Sofia field and K_{Rs}=0.17 for the Thracian Lowland

$$R_s = k_{Rs}\sqrt{(T_{\max} - \mathrm{T}_{\min})}\,\mathrm{R}_a \qquad (2)$$

where R_a extraterrestrial radiation [MJ m^{-2} d^{-1}], T_{max} maximum air temperature [°C], T_{min} minimum air temperature [°C], k_{Rs} adjustment coefficient (0.16.. 0.19) [$°C^{-0.5}$].

Procedures to estimate missing humidity relate to the use of minimum temperature data and those for the wind speed data refer to adopting regional average data. The accuracy of all different procedures analysed is assessed by regressing *ETo* values calculated with the FAO-PM equation computed with limited data versus *ETo* values computed with complete data sets (fig.4; tables 6 and 7).

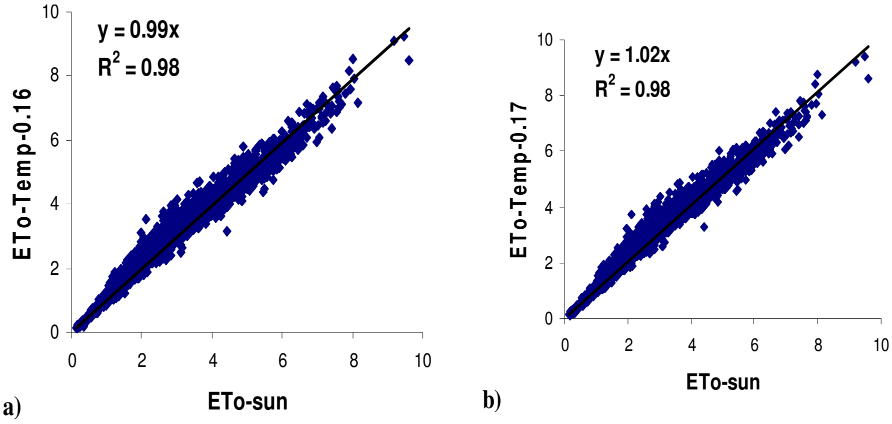


Fig.4. Comparing daily ET_o –PM (mm day^{-1}) computed for Tsalapitsa (Jan-Dec, 1985-1991) when R_s is estimated from temperature differences (ET_o – Temp) and sunshine duration is observed (ET_o – sun): a) $k_{Rs}=0.16$; b) $k_{Rs}=0.17$.

Table 6. Results from computing ET_o estimates with full data sets with ET_o computed with solar radiation estimated from maximum and minimum temperature differences. (eq.2)

Location	***Plovdiv-NIMH***	***Stara Zagora***	***Tsalapitsa***
	Town	***Airport***	***Field***
Observation period	1980-1984 *Jan-Dec*	1976 *Apr-Sept*	1985-1991 *Jan-Dec*
R_s from T_{max} and T_{min}, $k_{Rs}=0.16$			
Regression coefficient b	0.99	1.03	0.99
R^2	0.96	0.86	0.98
***RMSE* (mm d^{-1})**	0.22	0.32	0.18
R_s from T_{max} and T_{min}, $k_{Rs}=0.17$			
Regression coefficient b	1.02	1.07	1.02
R^2	0.96	0.85	0.98
***RMSE* (mm d^{-1})**	0.22	0.40	0.17

Table 7. Regression parameters and RMSE characterizing alternative procedures for estimating ETo-PM from maximum and minimum temperature only.

	Plovdiv-NIMH	***Tsalapitsa***	***Stara Zagora Airport***
Observation period	1980-1984 *Jan-Dec*	1985-1991 *Jan-Dec*	1976 *Apr-Sept*
ETo-PM R_s from T_{max}-T_{min} (eq.2); e_a from T_{min}; u_2=1.68m/s	**$K_{Rs}=0.17$**	**$K_{Rs}=0.17$**	**$K_{Rs}=0.16$**
Coefficient b	1.03	0.94	1.07

R^2	0.85	0.81	0.50
***RMSE* (mm d^{-1})**	0.52	0.58	0.68
Hargreaves' equation			
Coefficient b	1.11	1.01	1.19
R^2	0.86	0.82	0.56
***RMSE* (mm d^{-1})**	0.60	0.62	0.86

Statistical parameters of the regression through the origin and the computed standard errors of estimates, *RMSE*, are used. It could be concluded that the procedures proposed by FAO are accurate providing small *RMSE* including when only maximum and minimum temperature data are used, which yields lower *RMSE* than using the Hargreaves equation, which tends to overestimates *ETo* for the observed conditions.

2.2.3 Crop and irrigation experiments

Tsalapitsa experimental field

Independent historic datasets on seven years of experiments (1984–1990) relative to diverse maize irrigation treatments were used for calibration and testing the irrigation scheduling simulation model ISAREG. The maize hybrid variety H708 was grown in

(a) rainfed (treatment 1);

(b) full irrigation, with application of the required irrigation water depth, which was computed through a water balance performed in conjunction with soil water observations; water depths were applied when soil moisture dropped to 80% of field capacity in the root zone (treatment 2), or weekly or two times a week during the irrigation season (treatments 6 and 7);

(c) excess irrigation, with applications equal to 1.3 times the required irrigation water depth (treatment 3);

(d) mild stress, with application of 70% of the requirements, by continuously reducing the applied depth for all irrigations (treatment 4), or by reducing the application depths during selected periods: from 12-leaves to tasseling (i.e., development stage), tasseling to milky-ripening (mid-season), or milky-ripening to waxy-ripening (late season), respectively treatments 12, 13 and 14;

(e) stressed, with application of 40% of the required depth at every irrigation (treatment 5);

(f) highly stressed, with application of 20% of the required depth during selected periods: 12-leaves to tasseling, tasseling to milky-ripening, and milky-ripening to waxy-ripening (respectively treatments 9, 10 and 11).

The actual crop evapotranspiration (ETa) was estimated for the periods “12-leaf to tasseling”, “tasseling to milky-ripening”, and “milky-ripening to waxy-ripening”, which correspond to the main crop growth stages. ETa was computed by performing the soil water balance with a daily time step throughout the vegetation season. The soil water balance was performed by using all observed variables and included the estimation of deep percolation of excess irrigation and precipitation (Varlev et al., 1994).The irrigation water was applied through short blocked furrows.It was measured volumetrically with help of field metallic reservoirs,whose water volumes were measured just before and after the irrigation events; measurements errors were smaller than 0.3%. Rainfall and the remaining climate variables were observed near by the experimental plot. Further information relative to the referred experiments is available (Kirkova et al., 1988; Kirkova, 1994; Varlev, 1988, 2008; Varlev et al., 1989, 1990, 1994; Varlev and Popova, 1999).

Pustren experimental field

Irrigation experiments were carried out in Pustren station for twenty consecutive years (1972-1992), with only two exceptions where data was invalidated due to a thunderstorm that destroyed the crop in 1975, and to technical problems in 1979 (Eneva, 1993). Two maize late hybrid varieties, namely a Bulgarian one, Kn-2L-611, and an American one, H708, were grown on the experimental plot in two consecutive periods: 1972-1980 for the former and 1981-1992 for the latter. Fertilisation consisted of the following rates: nitrogen (N) 150 kg/ha; potassium (K) 100 kg/ha; and phosphorus (P) 100 kg/ha.

For the current study one rainfed and four irrigation treatments were performed on plots of 100 m^2 area each with four replications. Irrigation treatments consisted of: (a) full irrigation with applications of the required irrigation water depth ; (b) mild stress with application of 75% of the required depth; (c) stressed with application of 50% of the required depth; and (d) fully irrigated except for the period 1-20.08 during which no irrigation was applied. The required irrigation depth was computed from the soil water balance. Irrigation was performed as soon as soil moisture dropped to 80% of field capacity (FC) in the top 60 cm of the soil layer, from planting to the tasseling growth stage, and in the top 100 cm from then to harvest.

Observed crop parameters consisted of dates of growth stages and grain yield. The dates limiting each growth stage were evaluated when 25 out of 100 observed plants attained that stage in every replication. Yield was observed in harvested plots of 25 m2 inside each replication plot. The yield was evaluated at 13% standard grain moisture and results were checked for errors by a dispersion statistical analysis (Eneva, 1993). The soil water content was observed by the gravimetric method not less than twice a week during the maize vegetation season. The crop evapotranspiration was assessed for the periods corresponding to the main stages of crop development by performing the water balance using all observed variables. Irrigations were performed in such a way that percolation was avoided for all treatments. Water volumes were measured by an automatic water-meter and applied on the surface through short blocked furrows. Rainfall was observed in the experimental plot. The ground water table is below 10 m depth, thus not contributing to crop water use. Detailed information relative to these experiments is published by Eneva (1993; 1997a; and 1997b).

2.3 Calibration parameters of the WinISAREG model

Crop coefficients Kc

Crop factors refer to four crop growth periods: initial, crop development, mid-season and end season. Crop evapotranspiration (ETc) is computed using the single crop coefficient approach (Allen et al., 1998):

$$ET_c = \mathbf{K_c}\ ET_o \qquad (3)$$

The actual evapotranspiration (ETa) is computed through the model as a function of the available soil water in the root zone when depletion exceeds the depletion fraction for no stress (p) as explained by Teixeira and Pereira (1992) and Liu et al. (1998).

Soil water depletion fractions p

The optimum irrigation threshold to avoid water stress is when the actual soil water content θ_i equals the threshold relative to the depletion fraction for no stress p, $\theta_i = \theta_p$

$$\theta_p-\theta_{WP} = (1-\mathbf{p})*TAW = (1-\mathbf{p})(\theta_{FC}-\theta_{WP}), \qquad (4)$$

where **TAW** is total available water capacity, θ_{FC} is soil water content at field capacity, θ_{WP} is soil water at wilting point, **z** – rooting depth

Yield response factor Ky

Yield impacts of water stress are assessed with the Stewart onephase model (Stewart et al., 1977; Doorenbos and Kassam, 1979). This approach was validated for Southern Bulgaria (Popova et al., 2006b; 2011). The yield response factor Ky characterizing the crop yield response to water deficit is defined as the ratio between the relative yield decrease and the relative evapotranspiration deficit as:

$$\mathbf{(1-}Ya/Ymax\mathbf{)} = \mathbf{Ky\ (1-}ETa/ETmax\mathbf{)} \qquad (5)$$

where ETa and ETmax are respectively the actual and the maximum (potential) ETc [mm], and Ya and Ymax are the corresponding yields [kg/ha] obtained when ET equals respectively ETa and ETmax. Ky = 1.32 was derived from all experimental data but excluding results from highly stressed treatments, i.e., when (1–ETa/ETmax) > 0.5, and from years when the maximum yield was affected by stress.

2.4 Model calibration and validation procedures

The ISAREG model is an irrigation scheduling simulation model that performs the soil water balance at the field scale as described by Teixeira and Pereira (1992), Liu et al. (1998) and Pereira et al. (2003). The latter describes the version used in this study. Inputs are precipitation, reference evapotranspiration (ETo), total and readily readily available soil water, soil water content at planting or first day of simulations, crop factors relative to crop growth stages, crop coefficients, root depths, depletion fractions for no stress, and water-yield response factors. Crop factors refer to four crop growth periods: initial, crop development, mid-season and end season. Crop evapotranspiration (ETc) is computed using the single crop coefficient approach (Allen et al., 1998). The actual evapotranspiration (ETa) is computed from ETc as a function of the available soil water (Teixeira and Pereira, 1992; Liu et al., 1998). ISAREG includes auxiliary programs to compute ETo and the crop factors.

The soil water balance was performed with a daily time step as:

$$SWi = SWi-1 + Pe,i + Ii + Gc,i - ETa,i - Dr,i \qquad (6)$$

where SWi and SWi−1 are respectively the soil water content in the crop root zone at the end of days i and i−1 [mm]; Pe,i is the precipitation on day i [mm]; Ii is the net irrigation depth on day i that infiltrates the soil [mm]; Gc,i is the capillary rise from the groundwater table on day i [mm]; ETa,i is the actual crop evapotranspiration on day i [mm], Dr,i is the deep percolation out of the root zone on day i [mm]. Gc,i was neglected because the groundwater table was generally below 10m depth; Dr,i was computed by the model as described by Liu et al. (2006).

The calibration and validation of the ISAREG model was performed by using the maize datasets referred above. The calibration of the model consists of searching the crop coefficients Kc and the depletion fractions for no stress p relative to the initial, mid season and end season crop stages that provide for minimal differences between observed and simulated soil water. The methodology described by Popova et al. (2006b) and Cholpankulov et al. (2008) was adopted.

Tsalapitsa field

Data for 1988 treatments 1 and 2, respectively rainfed and full irrigated maize, were used for model calibration; the initial values for Kc and p used in the iterative search procedure were those proposed by Allen et al. (1998) after adjustment for climate. The dates for the crop development stages, as well as irrigation dates and depths, were those observed in the field. The derived Kc and p parameters were validated using the data sets for the remaining 10 treatments of that year. The model was further validated by comparing the season ETa and the relative evapotranspiration ei = ETa/ETmax simulated by the model with the observed seasonal values for all rainfed and irrigation treatments over the period 1984–1990.

Pustren field

Data for 1976 were used for model calibration; the initial values for Kc and p used in the iterative search procedure were those proposed by Allen et al. (1998) after adjustment for climate. The dates for the crop development stages, as well as irrigation dates and depths, were those observed in the field. The derived Kc and p parameters were validated using the data sets for 1987.

The accuracy of the model was further tested against experimental long-term data by comparing the season actual crop evapotranspiration observed for the rainfed and irrigation treatments (Eneva, 1993, Eneva, 1997a and Eneva, 1997b) against the simulated values for the whole period 1972-1990. Simulations for the irrigation treatments were performed using the irrigation depths and dates as they were actually applied in the field experiments.

The yield response factor Ky was derived from the observed data sets by regressing the experimental evapotranspiration deficit data against the corresponding yield deficits. In full Ky is defined by the ratio between the yield deficit and the evapotranspiration deficit (Eq. 5):

The model was further tested adopting the derived Ky values by comparing the relative yield decreases (Ymax-Ya)/Ymax observed and computed by the model. For all comparisons a regression through the origin was used, as well as the average error of estimates (AEE) that characterises the absolute deviation of simulated from the observed variables (Liu et al., 1998).

2.5 Goodness-of-fit

The first approach to assess the goodness-of-fit consisted in analyzing the graphical representation of model simulated soil water content compared with observed values. This allows a good perception of trends or bias in modelling when they occur. A second approach was to perform a regression forced to the origin relating observed and model predicted values. The regression and determination coefficients were defined as:

$$b = \frac{\sum_{i=1}^{n}\left(O_i - \overline{O}\right)\left(P_i - \overline{P}\right)}{\sum_{i=1}^{n}\left(O_i - \overline{O}\right)^2} \qquad (7)$$

$$R^2 = \left\{ \frac{\sum_{i=1}^{n}\left(O_i - \overline{O}\right)\left(Pi - \overline{P}\right)}{\left[\sum_{i=1}^{n}\left(O_i - \overline{O}\right)^2\right]^{0.5}\left[\sum_{i=1}^{n}\left(P_i - \overline{P}\right)^2\right]^{0.5}} \right\}^2 \qquad (8)$$

where Oi and Pi (i = 1, 2, …, n) are pairs of observed and model predicted values of a given variable and $\overline{O}$ and $\overline{P}$ are the respective mean values, If the regression coefficient (b) is close to 1 then the covariance is close to the variance of the observed values, i.e., the predicted values are statistically close to the observed ones; when the determination coefficient (R^2) is also close to 1.0 then most of the variation of the observed values is explained by the model.

In addition, a set of indicators of residual estimation errors is used. Indicators are based upon former applications in hydrology (Green and Stephenson, 1986; Loague and Green, 1991; Legates and McCabe, 1999; Coffey et al., 2004; Moriasi et al., 2007; WWRP/WGNE, 2007). Adopting the same symbols as for Eqs. 7 and 8, the indicators were defined as:

The root mean square error (same units as Oi), which characterizes the variance of the errors

$$\mathrm{RMSE} = \left[\frac{\sum_{i=1}^{n}\left(P_i - O_i\right)^2}{n}\right]^{0.5} \qquad (9)$$

The average absolute error (same units as Oi), which expresses the size of estimation errors in alternative to RMSE

$$AAE = \frac{1}{n}\sum_{i=1}^{n}\left|O_i - P_i\right| \qquad (10)$$

The average relative error (%), that indicates the size of errors in relative terms

$$ARE = \frac{100}{n}\sum_{i=1}^{n}\left|\frac{O_i - P_i}{O_i}\right| \tag{11}$$

The maximum absolute error (same units as Oi)

$$\text{Emax} = \text{Max } \left|P_i - O_i\right|_{i=1}^{n} \tag{12}$$

Errors of estimate calculated by equations above provide good information about the accuracy of model predictions. Generally an ARE value below 10% may be considered low,

Other statistical indicators used are:

The modelling efficiency (non-dimensional), developed by Nash and Sutcliff (1970), It is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance (Moriasi et al., 2007). It is defined by the ratio of the mean square error to the variance in the observed data subtracted from the unity.

$$EF = 1.0 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}\left(O_i - \overline{O}\right)^2} \tag{13}$$

If the square of the differences between the model simulations and the observations is as large as the variability in the observed data, then EF = 0.0 and the observed mean, $\overline{O}$, is as good a predictor as the model while negative values indicate that $\overline{O}$ is a better predictor than the model (Legates and McCabe, 1999; Moriasi et al., 2007).

The index of agreement (non-dimensional) developed by Willmott (1981). It represents the ratio between the mean square error and the "potential error". The author defined potential error as the sum of the squared absolute values of the distances from the predicted values to the mean observed value and distances from the observed values to the mean observed value (Moriasi et al., 2007). It may be defined as

$$d_{IA} = 1 - \frac{\sum_{i=1}^{N}(O_i - P_i)^2}{\sum_{i=1}^{N}\left(\left|P_i - \overline{O}\right| + \left|O_i - \overline{O}\right|\right)^2} \tag{14}$$

It is a standardized measure of the degree of model prediction error and varies between 0 and 1. A computed value of 1 indicates a perfect agreement between the measured and predicted values, and 0 indicates no agreement at all (Legates and McCabe, 1999; Moriasi et al., 2007).

2.6 Irrigation scheduling alternatives adapted to local conditions and water saving practices

Simulations with ISAREG model were performed adopting soil water thresholds and application depths defined from previous experiments of furrow irrigation for the same soils. Net irrigation requirements (NIR) calculated with the model using weather data relative to

1970-1992 were used to identify the years of average and extreme irrigation demand. The alternative irrigation schedules simulated for these years are presented in Chapter 4.

First θi and then the required irrigation depths In_i are calculated when the appropriate thresholds for the soil water are reached:

$$In_i = 100\ z_{ri}(\boldsymbol{\theta}_{FC} - \boldsymbol{\theta}_p) \qquad (15)$$

The net irrigation requirements (NIR) are refered to the theoretical irrigation requirements of a crop, not considering the water supply method. This way, NIR only satisfy the crop transpiration needs so it does not present yield losses.

Irrigation is scheduled when the management-allowed depletion, MAD, is attained. When water stress is not admitted, then MAD = p; a MAD < p is adopted when there is risk aversion (e.g. deep percolation losses in case of soil cracking) or uncertainty, and MAD > p when crop water stress is allowed,

$$In_i = 100\ z_{ri}(\boldsymbol{\theta}_{FC} - \boldsymbol{\theta}_{MAD}) \qquad (16)$$

and the applied depth is either a user selected fixed quantity D (mm), or a variable $D = \theta_{FC} - \theta_i$. Thus the irrigation demands (ID) are determined as cumulation of application depths (In_i) taking into account the chosen irrigation scheduling alternative.

Case study on Vertisol at Pustren

Past studies on continuous and surge-flow furrow irrigation carried out at Pustren field (Popova, 1990; Popova et al., 1994; 1998; Popova & Kuncheva 1996; Varlev et al., 1998) have shown that the distribution uniformity is high and deep percolation might be practically avoided when the soil water content is maintained above the cracking level, which is about 80-82% of field capacity for Vertisols. Results of inflow-outflow measurements under such conditions show that the average infiltrated depth in a furrow set is within the range 80-100 mm for continuous furrow irrigation. Results for surge irrigation have shown that further improvements on the distribution uniformity could be reached and the application depths could be reduced by 18-25%. Irrigation scheduling alternatives were based on these results and are the following:

1. Alternative 1: relates to furrow irrigation with continuous flow and consists of refilling the soil reservoir and adopting a management allowed depletion fraction (MAD) of 0.47, thus with application depths of 90 mm. The total available water (TAW), defined from the difference between the stored soil water at field capacity and the wilting point considering 1.10 m soil root depth, is 193 mm,

2. Alternative 2: refers to furrow surge flow and consists of refilling the soil reservoir to TAW adopting MAD = 0.33 and application depths of 60 mm.

3. Alternative 3: aims at better storage and use of precipitation and irrigation water, thus it consists of refilling up to 84% of TAW (162 mm) adopting MAD = 0.47 and application depths of 60 mm. About 30 mm of the soil reservoir are not refilled to better accommodate for any precipitation occurring after the irrigation event.

4. Alternative 4: crop without irrigation.

Case study on Chromic Cambisol soil at Zora

The following irrigation scheduling alternatives are generated for surge furrow irrigation in the **Chromic Cambisol soil at Zora** site, Stara Zagora:

(2) Refilling the soil reservoir and adopting a MAD of 0.60 when the application depths are 90 mm;

(3) Refilling the soil reservoir and adopting MAD=0.40, thus with application depths of 60 mm;

(4) Partially refilling soil reservoir with application depths of 60 mm but adopting MAD=0.60.

According to the actual irrigation practice in Thrace region and former studies (Zahariev et al., 1986), the last irrigation should not be scheduled after 15 August. This condition is considered for all irrigation scheduling alternatives in addition to a free definition of the irrigation timings

3 RESULTS ON CALIBRATION AND VALIDATION OF MAIZE IRRIGATION SCHEDULING IN BULGARIA

3.1 Calibration, Validation and further testing of the irrigation scheduling simulation model ISAREG

The WinISAREG model (Pereira et al.,2003) is used in this study after previous calibration. It is a simulation tool for computing the soil water balance, generating alternative irrigation schedules and evaluating the respective water stress impacts on crop yields.

The ISAREG model has been validated and applied in several regions and for maize crop to develop improved irrigation scheduling practices leading to more efficient water use and water saving, and to predict impacts of water stress on yields.

3.1.1 Crop coefficients Kc and yield response factors Ky at Pustren, Zora and Tsalapitsa fields

The calibration of the model consists of deriving crop coefficients ***Kc*** **(fig.5, table 8)*,*** ratio between crop and reference evapotranspiration, and depletion fractions ***p*** for no stress, i.e. the soil water fraction that may be extracted by the crop without causing water stress, relative to the main crop growth stages, thus adapted to local climate and soil conditions, through searching the minimal differences between observed and model simulated soil water content - θ (fig.6; table 8).

The calibration relative to **Pustren** and **Zora** is performed using data for 1976 (fig.6), while data for 1987 are used for validation (tabl.9) (Popova, Eneva, Pereira 2006; Popova 2007, 2008).

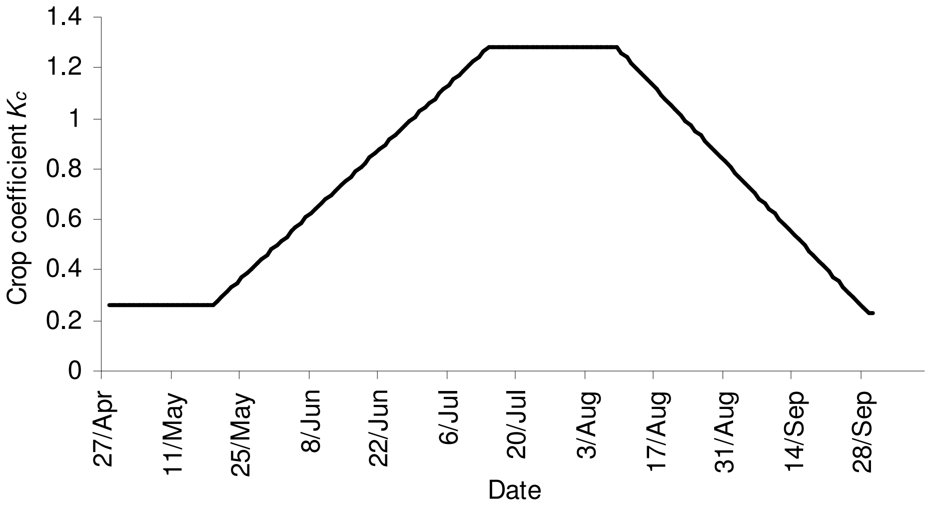


Figure 5 Crop coefficient curve for maize hybrid H708 at Pustren (Stara Zagora) for 1976 (Popova et al., 2006).

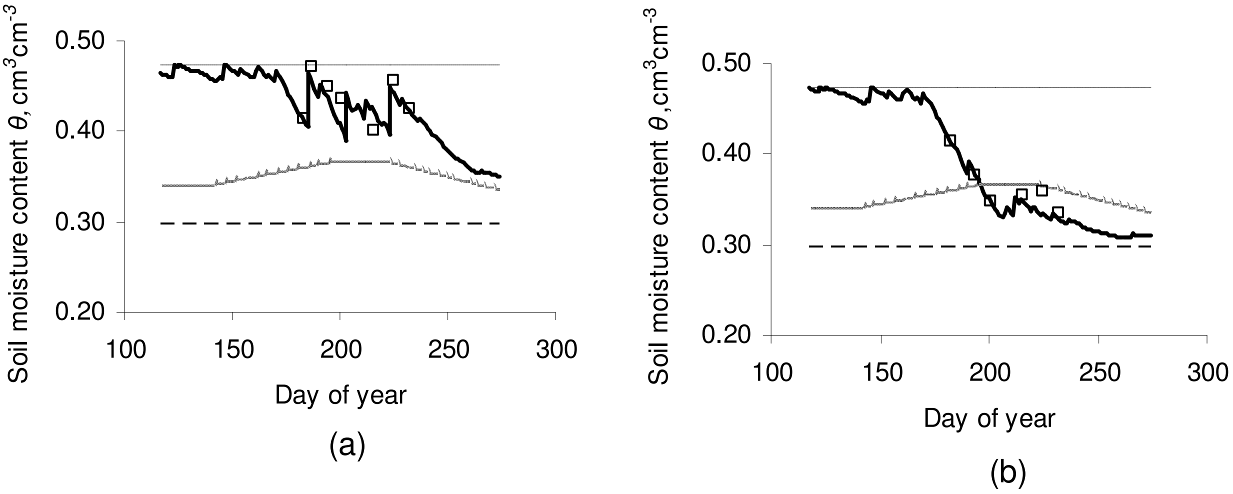
Table 8. Dates and crop development stages and model calibration parametres : Kc at Pustren

Crop development stages	Initial stage	Mid-season	End season period (harvest)
Dates	26/04.- 19/05	15/07 - 09/08	30/09
Kc	0.28	1.28	0.23
p	0.45-0.75	0.60	0.78

The resulting average absolute errors of the estimate (*AEE*) for the soil water content are respectively 0.012, 0.013 and 0.023 cm^3 cm^{-3} (tables 9, fig.7), thus indicating appropriate model parameterisation.

Table 9. Statistical parameters relative to the model predicted soil water content θ during calibration (1976) and validation (1987), Pustren and Zora.

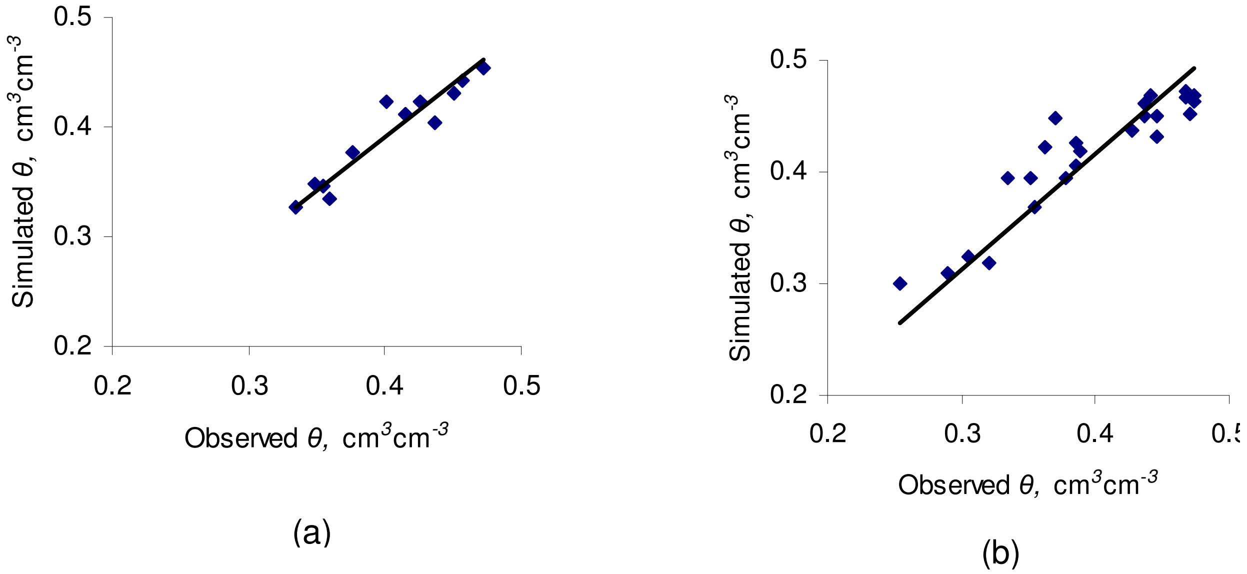
Year	***b***	R^2	***AEE***, cm^3cm^{-3}
1976, Calibration , *Pustren*	0.979	0.90	0.012
1987, Validation , *Pustren*	1.041	0.76	0.027
1976, Validation, *Zora*	0.987	0.86	0.013



(a)

(b)

Fig.6. Field observations (□) and ISAREG simulation of soil water content θ (-), **1976**: a) optimum irrigation b) rainfed maize, Pustren field. θ_{WP}; ——— θ_{FC}; ——— optimum yield threshold θ_P.



(a)

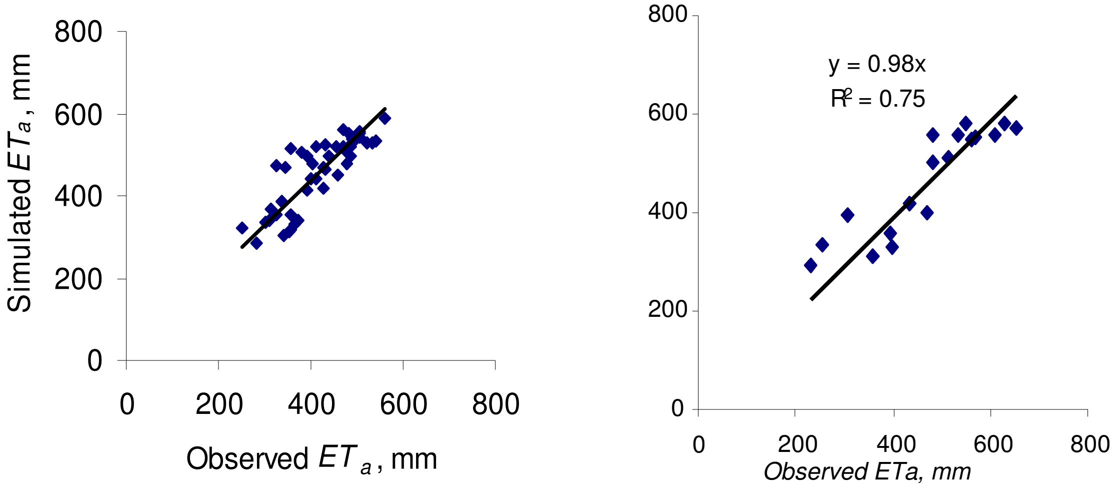
(b)

Fig.7 One-to one graphs comparing simulated with observed soil water content relative to the year of model calibration 1976 (a) and validation 1987 (b), Pustren site, Stara Zagora.

The accuracy of the calibrated model is tested against experimental long-term data from all irrigation and rainfed treatments (1972-1992 see Eneva; 1993, 1997 a; 1997 b in Vurlev, 2008) by comparing the computed versus observed seasonal evapotranspiration. Results show a regression slope close to the 1:1 line and an ***AEE*** relatively small: 49.75 mm/season at Pustren and 48.00 mm/season at Zora, which is less than 10% of the average evapotranspiration observed (table 10; fig. 8).

Table.10. Regression parameters and absolute error of estimate (AEE) characterising the deviation of simulations from field observations for the seasonal evapotranspiration at Pustren and Zora sites.

	Pustren			***Zora***
Period	1972-1980	1981-1990г	1972-1990г	1972-77 & 1983-85
Hybrid	Kn-2L-611	H708	Kn-2L-611 и H708	
ETa, mm				
b	1.13	1.05	1.09	0.98
R^2	0.45	0.88	0.68	0.75
AEE, mm	62.1	35.8	49.7	48.00
ETa/ETmax				
b	1.01	0.98	1.00	0.98
R^2	0.43	0.61	0.63	0.61
AEE	0.087	0.070	0.078	0.071

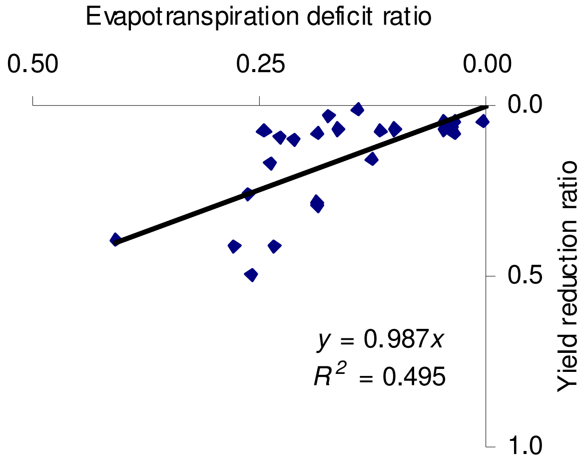


(a)

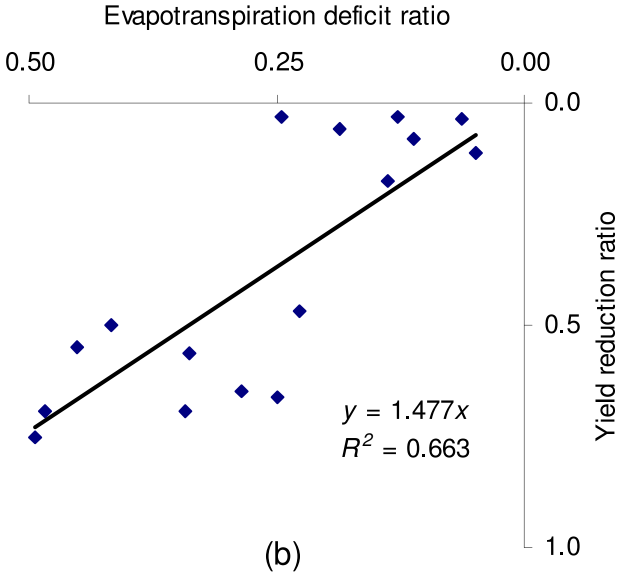
(b)

Fig.8 Comparing simulated and observed seasonal ET_a (mm) for the complete set of irrigation and rainfed treatments at Pustren over the whole period 1972-1990 (a) and Zora for the periods 1972-1977 and 1983-1985 (b).

The yield response factor ***Ky***, which relates relative yield decreases with the relative evapotranspiration deficits, is also derived from the observed data sets for the two hybrids used, resulting in a value of 1.0 for the hybrid *Kn-2L-611* adopted during the first decade (fig.9a) and a value of 1.5 for the hybrid *H708* used during the second one (fig.9b).



(a)



(b)

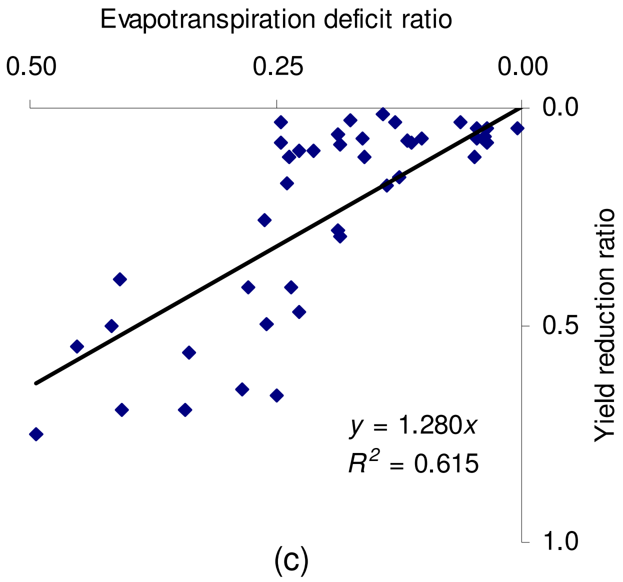


Fig.9. Estimation of yield response factor K_y from all observations in Pustren site, Stara Zagora, for the maize hybrid: (a) Kn-2L-611, 1972-1980 and (b) H708, 1981-1990; and (c) both hybrids, 1972-1990.

A statistical test is also performed to compare the model predicted versus observed relative yield decrease due to water stress for both varieties (fig. 9c). The regression coefficient ***b***=0.95 and ***AEE***=0.048 are obtained for the hybrid *Kn-2L-611* and respectively ***b***=0.96 and ***AEE***=0.067 for the *H708* (Table 11), which show that model predictions are appropriate. The obtained results support model use for developing water saving and environmentally oriented irrigation practices in the Thrace region, South Bulgaria.

Table 11. Regression parameters and AAE characterizing the deviation of simulated from field observed relative yield deficits for the maize varieties Kn-2L-611 and H708, Pustren, Stara Zagora.

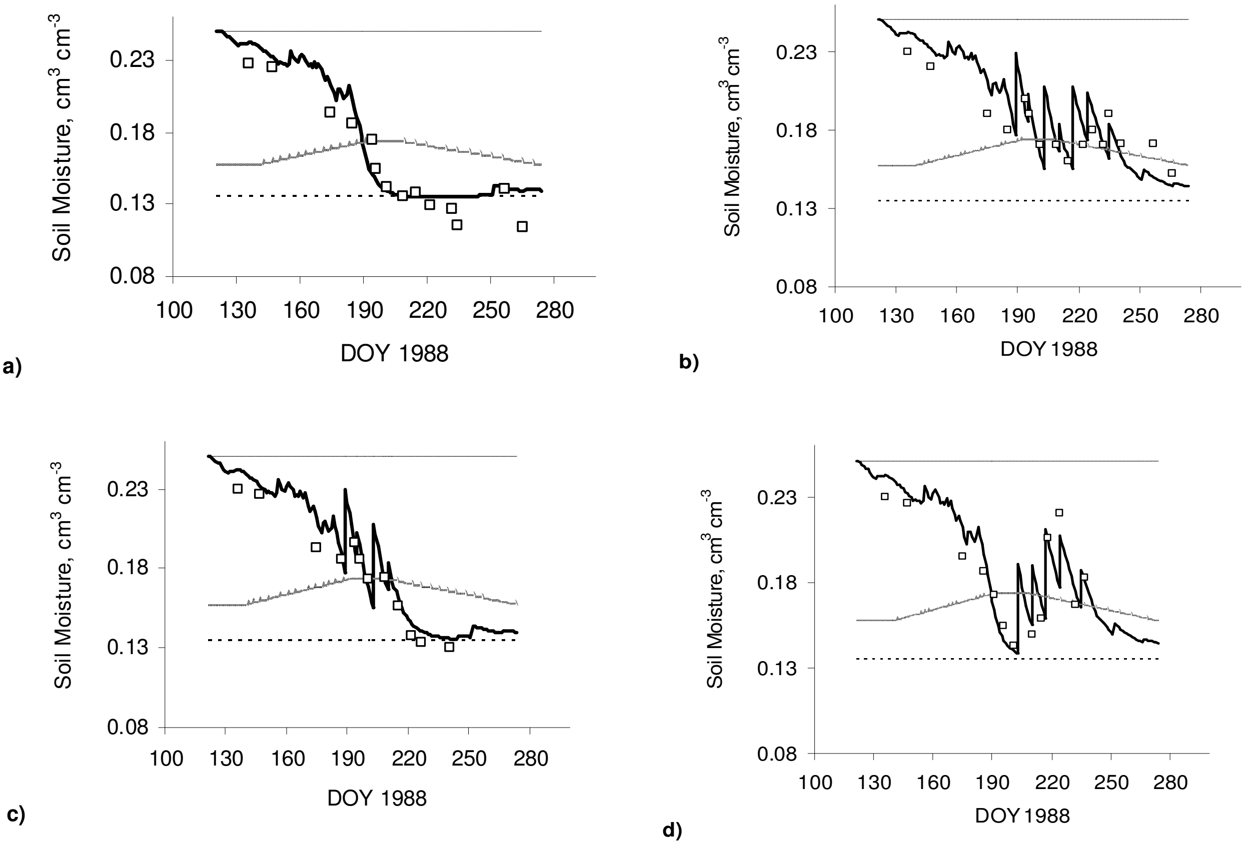
Period Hybrid	1972-1980	1981-1990	1972-1990	
	Kn-2L-611	***H708***	*Kn-2L-611* and *H708*	
K_y *(eq.13)*	1.0	1.5	1.5	1.0
b	0.952	0.958	1.036	0.714
R^2	0.79	0.83	0.82	0.74
AEE	0.048	0.067	0.082	0.109

The crop coefficients K_c and depletion fractions *p* for **Tsalapitsa**, Plovdiv region were derived when the model calibration was performed using data sets from the full irrigated (2) and the rainfed (1) treatments for 1988. The respective values are presented in Table 12.

Table 12. Dates of crop development stages and model calibration parameters: crop coefficients K_c and soil water depletion fractions for no stress p for maize at Tsalapitsa, 1988

Growth phases	*Dates*	K_c	p
Initial period	30/04 to 19/05	0.30	0.80
Mid-season period	10/07 to 26/07	1.26	0.66
End season	30/09 (harvest)	0.23	0.80

Results representing the model fitting of the observed soil moisture (SM) during the calibration test are presented in Figs. 10a and 10b as well as in Fig. 11, where simulated and observed SM data are regressed forced to the origin. Selected examples of the validation using the parameters obtained from calibration (Table 12) are shown in Figs. 10c-f and in Fig. 11b. Figs. 10c and d refer to mild stress treatments while Figs. 10e and 10f refer to highly stressed treatments.



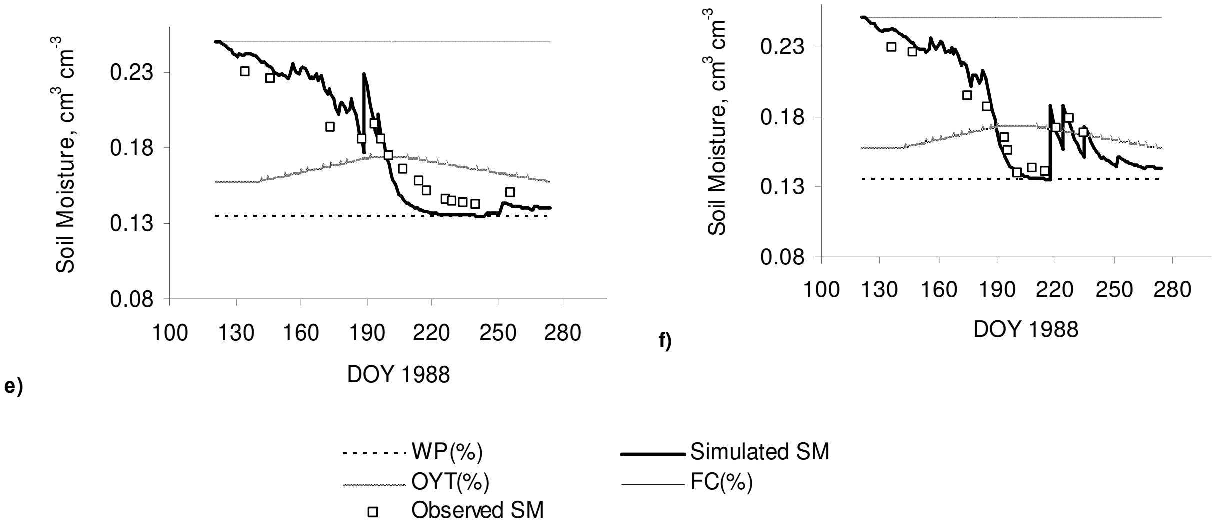


Figure 10. Observed and simulated soil moisture (cm^3 cm^{-3}) *versus* time (Day of year) relative to the model calibration for: (a) rainfed treatment 1; (b) full irrigation treatment 2; and validation for mild stress treatments 12 (c) and 13 (d) and high stress treatments 9 (e) and 11 (f). Tsalapitsa field, 1988

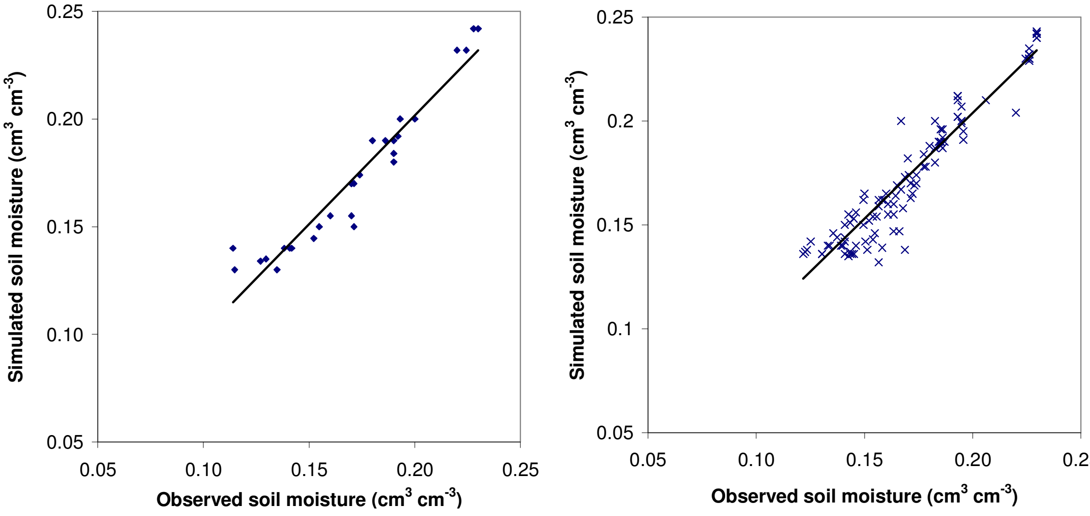


Figure 11. Comparing simulated versus observed soil moisture (cm^3 cm^{-3}) relative to: (a) the calibration treatments 1 and 2; and (b) the validation treatments 3 - 13; Tsalapitsa field, 1988

Results in Fig. 10 show that soil moisture simulations match well the observed values without apparent existence of trends or bias in modeling. Results in Fig. 11 and Table 13 show regression coefficients *b* close to 1 for both the calibration and validation, thus indicating that the calibrated parameters lead to predict soil moisture values statistically close to the observed ones. The determination coefficients are $R^2 = 0.92$ for both the calibration and validation, thus indicating that a large fraction of the variation of the observed values is explained by the model.

Table 13. Statistical indicators relative to the model fitting when comparing the predicted and observed soil water content during calibration and validation (1987) for all treatments of maize and the growth season, Tsalapitsa field

	b	R^2	$RMSE$ $(cm^3 cm^{-3})$	AAE $(cm^3 cm^{-3})$	ARE, (%)	$Emax$, $(cm^3 cm^{-3})$	EF	d_{IA}
Model calibration	1.01	0.92	0.01	0.01	4.19	0.03	0.91	0.98
Model validation	1.02	0.92	0.01	0.01	4.72	0.03	0.89	0.97

Results for the errors of model estimates are presented in Table 13. The estimation errors are small: AAE are 0.0067 and 0.0080 cm^3 cm^{-3} for the calibration and validation, respectively and RMSE are 0.01 cm^3 cm^{-3} for both the calibration and validation The indices of modelling efficiency and of agreement are high for both the calibration and validation, respectively EF = 0.89 and 0.91 and d_{IA} = 0.97 and 0.98. Results therefore indicate that the fitted crop parameters are appropriate and the model can be further used in the region.

Results for K_c (Fig. 5 and Tables 8 and 12) are compatible with those proposed by Allen et al. (1998). The value relative to the initial period corresponds to a low frequency of wettings; the mid-season value is slightly above the tabled values due to low air humidity and high wind during summer along the Thracian lowlands; and the end season value is adequate for harvesting with low grain moisture. Values obtained at Tsalapitsa (Table 12) are close to those previously estimated for the Stara Zagora region (Table 8). When comparing the calibrated crop coefficients obtained in this study for Tsalapitsa with those previously calibrated for Pustren, little differences are found in the K_c values. There are differences in the duration crop stages due to differences in climatic variables because comparisons refer to different years at both locations and crop phenology is different due to local climate features. The milky-ripening phase is observed to usually occur earlier in Tsalapitsa, on the average by 13 days, ranging 3 to 17 days. Results confirm that variations of crop coefficients from location to another are very small, negligible in the cases under appreciation, but the dates and durations of crop growth stages are quite variable and require appropriate field observations, i.e., differences in crop coefficient curves are mainly due to dates and durations of crop growth stages (Allen et al., 1998).

The initial and final *p* values (Table 12) are higher than expected but they have little influence on the simulation results: the first because soil moisture is very often high at the initial stage considering the local climate, and the second because it refers to a date when the grain is dry. The value for p at mid season is also higher than usual because irrigation management under surface irrigation has to allow a relatively high soil water depletion to accommodate for large irrigation depths. Results in Fig. 7 show that maize is managed with high management allowed depletions (MAD), thus with some water stress during the mid and late seasons.

Model predictions of the seasonal actual evapotranspiration ET_a and the ratio ET_a/ET_{max} for all treatments in 1988, Tsalapitsa field, are compared with the observed ones in Fig. 12. As reported before, the observed ET_a results from accurate soil water balance computations performed with short time step field observation data. The regression parameters show (Table 14) a tight correlation between simulated and observed ET_a and ET_a/ET_{max}: the regression coefficients b practically equal 1.0 (1.005 and 0.997) and the coefficients of determination are $R^2 = 0.97$. The seasonal estimation errors for ET_a are negligible: AAE 11.8 mm, RMSE = 15.6 and ARE = 3% of the average evapotranspiration observed in absolute values and 0.02 of those in relative terms. Confirming these results, very high fitting indicators were obtained: model efficiency EF = 0.97 and index of agreement d_{IA} = 0.99.

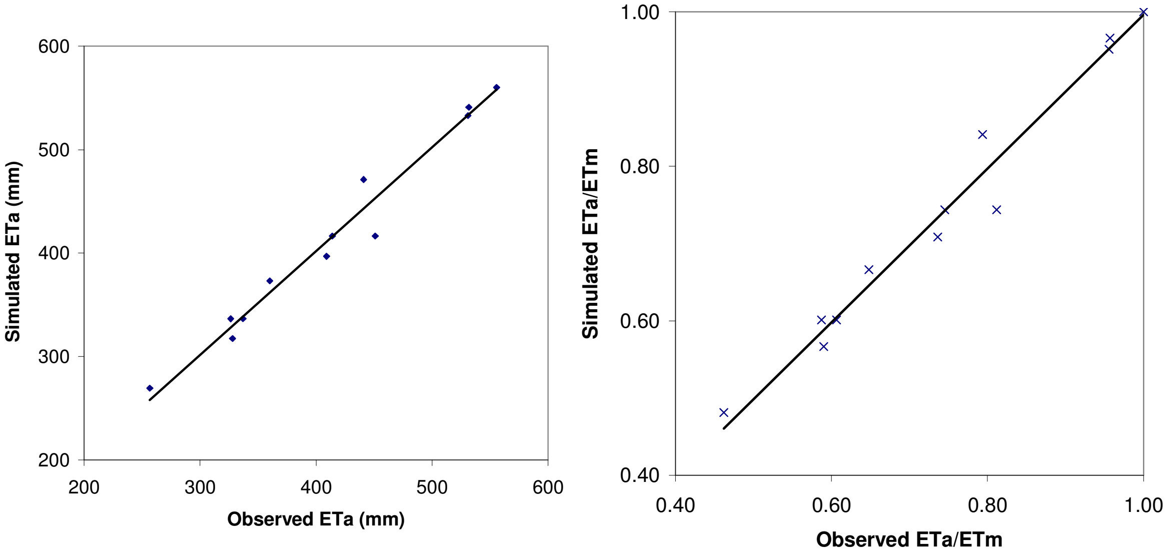


Figure 12. Comparing simulated and observed seasonal ET_a (mm) (a) and the ET_a/ET_{max} ratio (b) for the complete set of irrigation and rainfed treatments of 1988, Tsalapitsa field.

Model predictions of the seasonal actual evapotranspiration ET_a for all treatments in 1984-1990 are compared with the observed ones in Fig. 13. Separate comparisons are made for the "dry" and "wet" years, i.e., the seasons having higher and lower demand.

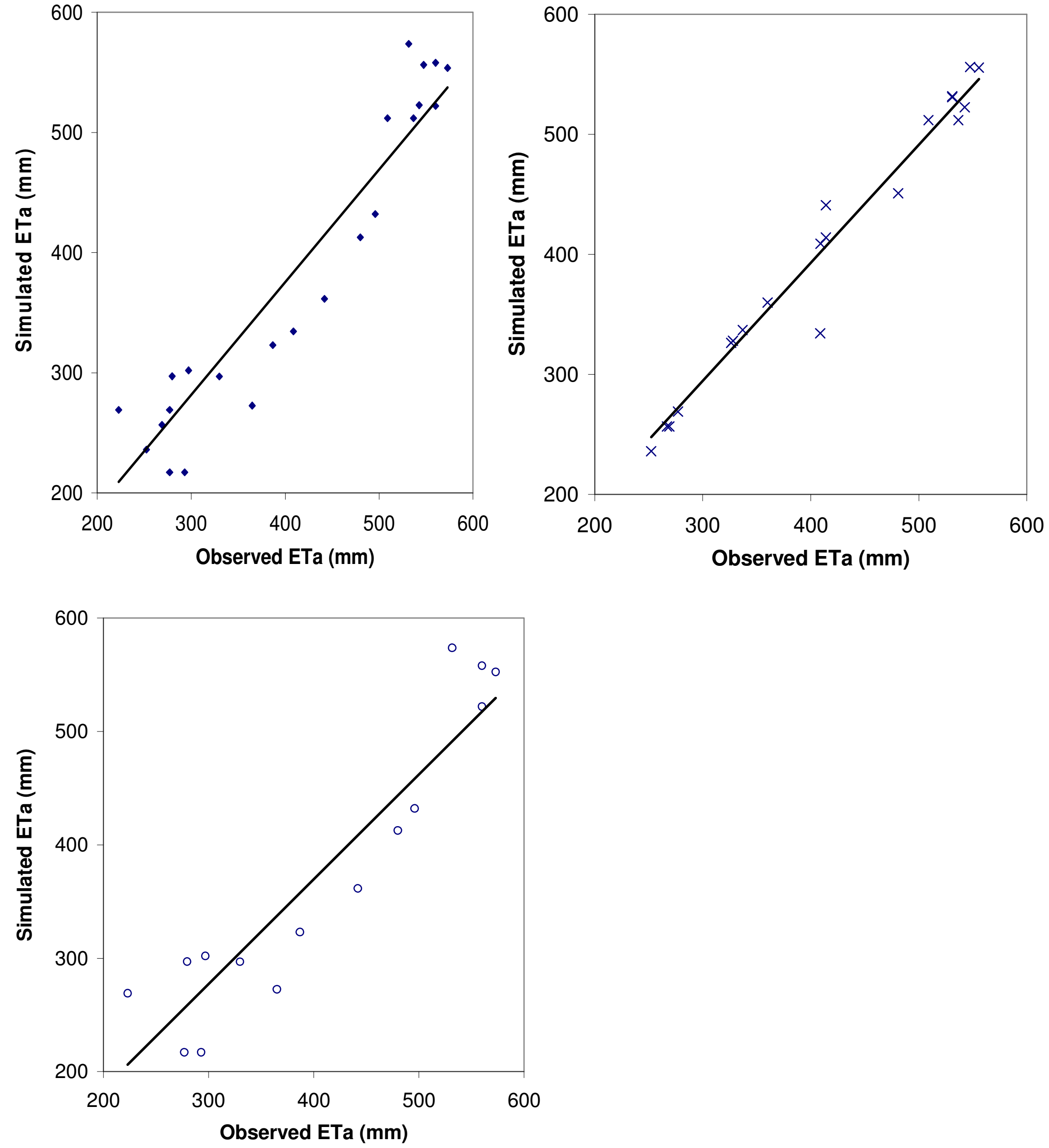


Figure 13. Comparing simulated and observed seasonal ET_a (mm) for the complete set of irrigation and rainfed treatments: a) over the whole period 1984-1990; b) for the "dry" years 1988-1990; c) for the "wet" years 1984-1987, Tsalapitsa field.

Table 14. Statistical indicators relative to the model goodness of fitting when comparing the predicted and observed seasonal evapotranspiration for all maize treatments, Tsalapitsa field

	b	R^2	*RMSE*	*AAE,*	*ARE,(%)*	*Emax,*	*EF*	d_{IA}
ET_a (mm), 1988	1.00	0.97	15.57	11.82	3.00	34.50	0.97	0.99
ET_a/ET_m ratio, 1988	1.00	0.97	0.03	0.02	2.82	0.07	0.97	0.99
ET_a (mm), 1984-90	0.94	0.91	47.22	37.99	10.17	92.30	0.84	0.96

ET_a (mm), “dry” years	0.98	0.97	21.00	11.75	2.96	74.30	0.96	0.99
ET_a (mm), ”wet” years	0.94	0.87	48.19	41.02	10.93	89.40	0.83	0.96

Results (Table 14) show that the model slightly underestimate ET_a as indicated by the regression slope $b = 0.94$. This underestimation is larger for the “wet” years than for the “dry” years, with regression coefficients of 0.94 and 0.98 respectively. The coefficient of determination is high for all experiments ($R^2 = 0.91$), and it is higher for those relative to “dry” years ($R^2 = 0.97$) than for wet years ($R^2 = 0.87$). The average error of estimates of the seasonal ET_a is small (Table 14): AAE = 38 mm for all experiments, AAE = 12 mm for the “dry” years and AAE = 41 mm for the “wet” years. These errors correspond to average relative errors of respectively 10, 3 and 11%. The difference between results for “dry” and “wet” years may be explained by the largest variability in precipitation and reference evapotranspiration for the wet years, when the computation of ET_a was likely to be less accurate. In addition, because calibration was performed for a “dry” year the adoption of the calibrated values for other years may be the cause for the observed underestimation. However, since the errors are small, it can be considered that the calibrated parameters are appropriate for maize irrigation management. The fitting indicators EF and d_{IA} are high (Table 14), e.g., $EF = 0.84$ and $d_{IA} = 0.96$ when all experiments are considered, thus confirming that model fitting is adequate:

Considering the regression parameters formerly obtained for the long-term crop coefficients validation for Pustren, Stara Zagora region, over the period 1981-1990 - b = 0.99, $R^2 = 0.872$ and AAE = 35.8 mm/season -, and for Zora in 1972-1977 and 1983-1985 - b = 0.99, $R^2 = 0.75$ and AAE = 48 mm/season, it may be observed that the model predictions of ET_a for Tsalapitsa, Plovdiv, are of similar accuracy and, therefore, the crop coefficients may be used in the Thracian plain. However, the dates and duration of crop growth stages need to be adjusted to local conditions, and the depletion factors for no stress need to be modified when surface irrigation is not used.

The value 1.32 for K_y derived from the experimental data sets relative to the hybrid variety H708 and relative yield decrease ($1-Y_a/Y_{max}$) smaller than 0.5 may be used with the model for generating or analysing maize irrigation schedules. With the purpose to assess the model ability to predict the relative yield decreases when using that Ky value, a statistical test was performed to compare the model predicted versus observed relative yield decrease YD due to water stress over the whole studied period 1984-1991 (Fig.14). Results show that the model slightly under-predicts YD since the regression coefficient b = 0.87 is smaller than 1. However, considering $R^2 = 0.91$, it can be concluded that the variation in evapotranspiration deficit explains most of variation in YD. The values AAE = 0.06 and RMSE = 0.07 indicates that the estimation errors are small. The observed underestimation may be due to the fact that the model slightly underestimates ET_a and because this analysis included all treatments while those producing large water stress were not considered when deriving K_y. The performance indicators obtained, $EF = 0.89$ and $d_{IA} = 0.97$, confirm that the yield modelling approach is adequate. Thus, that value $K_y = 1.32$ may be used with the Stewart model to predict the yield impacts of water deficits when selecting or analysing irrigation calendars for maize in the Thracian plain.

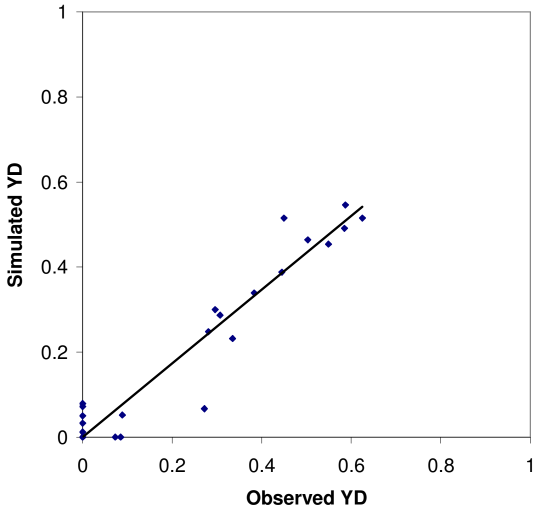


Figure 14. One-to-one simulated *versus* observed yield reduction ratio due to water deficit ***YD*** for the set of irrigation treatments relative to the whole period 1984-1991 (K_y=1.32 for maize), Tsalapitsa field.

The crop coefficients K_c and depletion fractions p for **Bozhurishte**, Sofia region (Table 15) were derived when the model calibration was performed using data using the data relative to the experiments in 2004 (Fig. 15), while data from 2003 and 2005 were used for validation (Table 16, Fig. 16).

Table 15. Dates of crop development stages and model calibration parameters: crop coefficients K_c and soil water depletion fractions for no stress p for maize at Bojurishte, 2004

Growth phases	*Dates*	K_c	p
Initial period	05/05 to 06/006	0.40	0.46-0.75
Mid-season period	01/08 to 01/09	1.28	0.60
End season	20/10 (harvest)	0.60	0.78

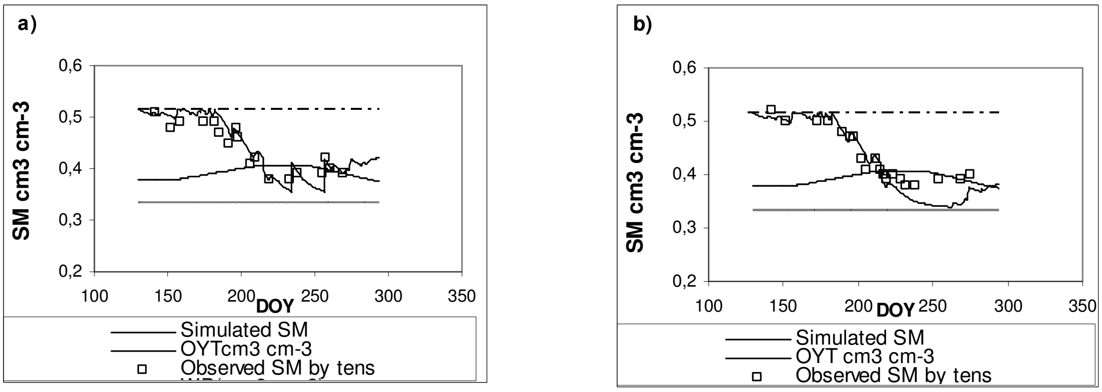


Fig 15. Field observations (□) and ISAREG simulation (-) of SM, cm^3 cm^{-3}: a) irrigated and b) rainfed maize, Sofia field, 2004

Table 16. Statistical parameters relative to the model predicted θ (soil water content) during calibration (2004) and validation (2003, 2005) of the model, Bojurishte site, Sofia field.

	b	*R^2*	*RMSE ($cm^3 cm^{-3}$)*	*AAE ($cm^3 cm^{-3}$)*	*ARE, (%)*	*EF*	*d_{IA}*
2004, calibration	1.00	0.88	0.03	0.014	3.11	0.87	98
2003, validation	0.99	0.66	0.02	0.020	4.55	0.69	92
2005, validation	1.02	0.58	0.015	0.015	5.15	0.65	88

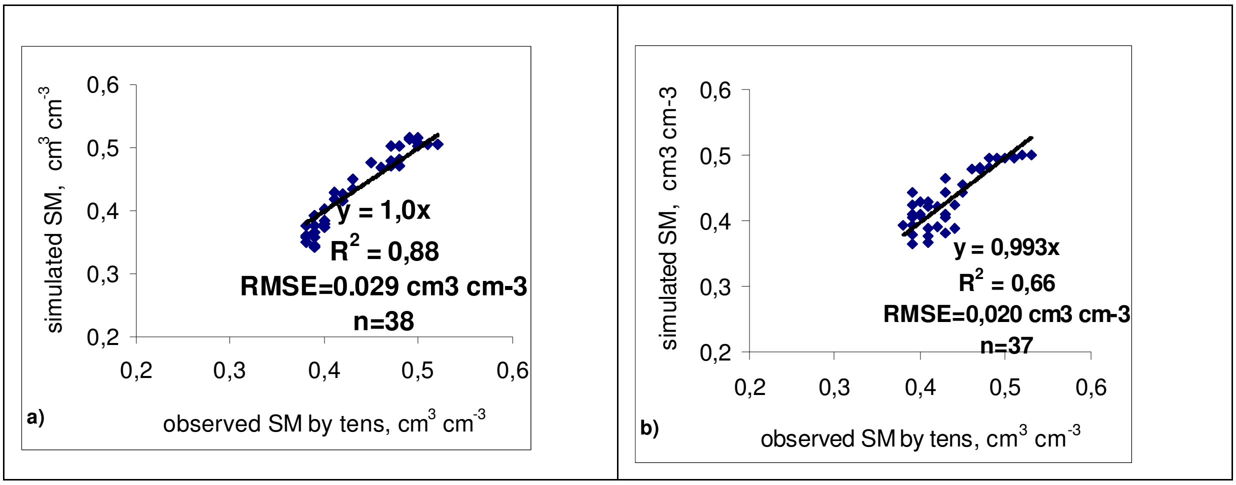


Fig. 16. Comparing simulated and observed soil moisture in the soil (SM, cm^3 cm-3) for the year of: a) calibration (2004г) and b) validation (2003) of model, irrigation and rainfed treatments; Bojurishte site, Sofia field.

4 SIMULATION RESULTS FOR PRESENT AND SCENARIO BUILT WEATHER CONDITIONS

4.1 Simulation results on net irrigation reuirements curves

Probility of exceedance curves if net irrigation requirements (NIR) for maize crop, relative to considered experimental fields in Sofia field and Tracian lowland are compared in Fig. 17.

The simulation results relative to present weather conditions (mainly 1960-1990) show that:Net irrigation requirements of maize NIRs in the vertisol (TAW=173mm m^{-1}), Stara Zagora range from 60-100 mm in wet seasons having probability of exceedance PI >95% to 180-230 mm in average demand seasons (40%<PI<75%) and reach 300-350 mm in extremely dry years (PI<5%). In the chromic cambisol (TAW=136 mm m^{-1}) at Zora, same region, irrigation requirements range from 60 to 400 mm, thus they are 35-55 mm larger over average and high irrigation demand years. NIRs at Tsalapitsa, Plovdiv (TAW=116 mm m^{-1}) are similar to these in Zora, except for the wet seasons (PI>80%) when NIRs are 30-60 mm larger. Compared to those relative to the chromic luvisol (TAW=106 mm m^{-1})in Sofia, NIRs at Zora (Fig.24b) are 80 mm larger over the average seasons (20%<P_I<70%).

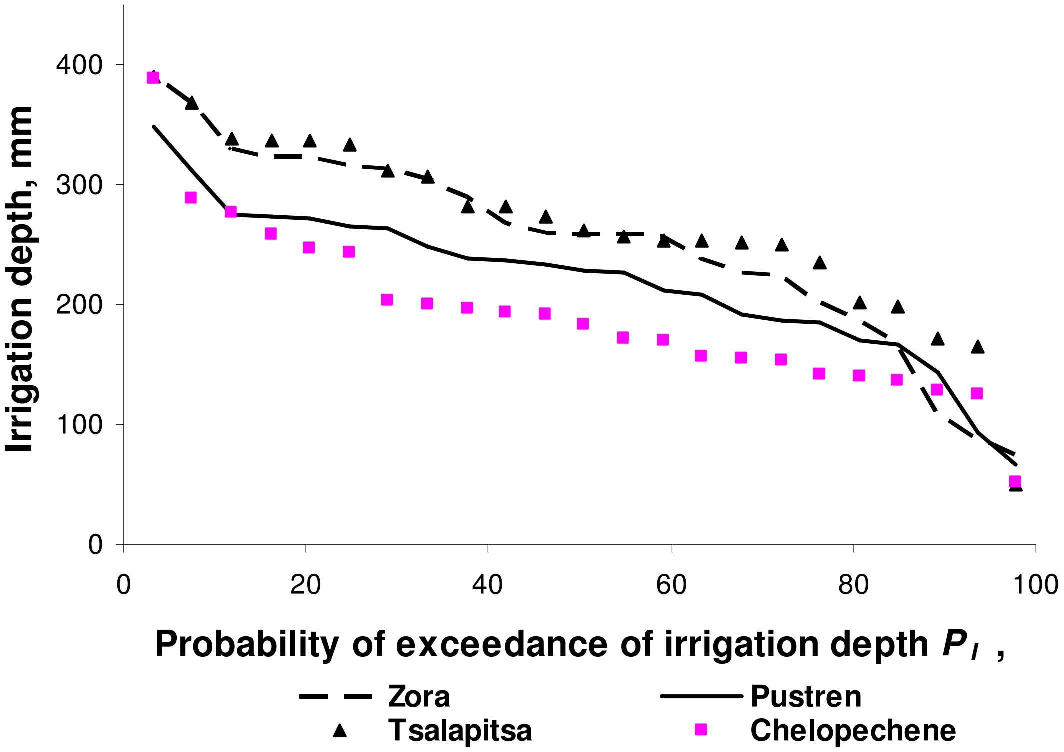


Figure 17. Comparison of probability curves of NIRs (mm) at: Pustren and Zora sites, Stara Zagora; Tsalapitsa field (Plovdiv) and Chelopechene site, Sofia field

4.2 Irrigation demands (IDs) under present weather conditions

Soil with high total available water (TAW=173 mm m^{-1}) capacity - Vertisol at Pastren, Stara Zagora

The results of the IDs simulations over the period 1970-1992 relative to the maize irrigation scheduling alternatives 1, 2 and 3 are shown in Fig. 18. It shows that considering the management allowed depletion fraction (MAD) and irrigation depths produce demands that may be lower or higher than NIR and that are different among them. The seasonal irrigation demands relative to the alternative 2, that refers to application depths D = 60 mm applied at high soil moisture (MAD = 0.33), is the highest among the IDs relative to the three alternatives and it is often larger than NIRs. Alternative 3, having the same D = 60 mm but scheduled with a larger soil water depletion (MAD = 0.47), refills the soil reservoir to only 84% of TAW and produces the smallest seasonal irrigation demands. In general, alternative 3 leads to water saving of about 60 mm when compared with alternative 2. The seasonal irrigation demand of alternative 1, which refers to MAD = 0.47 and application depths of 90 mm, is similar to that of alternative 3 in moderately wet and average crop seasons ($P_I = 40$ to 90%), and is between the irrigation demand values of alternatives 2 and 3 for dry crop seasons. These results show that allowing a higher soil water depletion, i.e. a larger MAD, favours water saving. However, for a vertisol, MAD is constrained by the critical soil water content to avoid soil cracking.

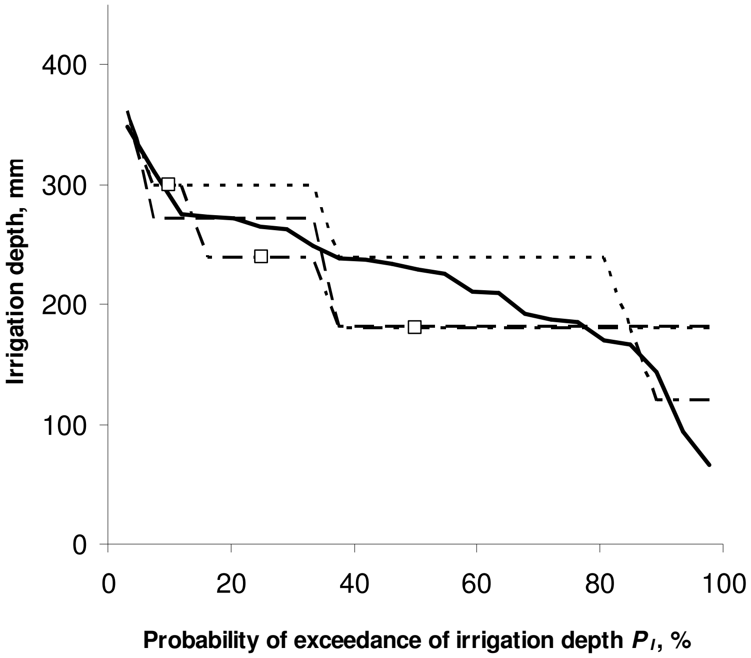


Fig. 18. Probability curves of net irrigation requirements, NIR (▬▬), and net season irrigation demand for the irrigation scheduling alternatives 1 (— —), 2 (▪ ▪ ▪ ▪ ▪) and 3 (—•—•), and for currently adopted scheduling (□), Pustren, Stara Zagora

Results of simulations of the available soil water (ASW) for the three irrigation scheduling alternatives are presented in Fig.19 for 1981, which is an extremely dry year ($P_I = 3\%$) in the period 1970-1992. The figure shows that alternative 1 requires 4 irrigation events of 90 mm each before 15/08 and alternatives 2 and 3 require 6 events of 60 mm; thus the same irrigation demand of 360 mm for all three alternatives. The full line in Fig. 4 refers to the ASW simulation when the last irrigation is applied before 15/08 and the dashed line refers to the last irrigation before 31/08. Results indicate that an irrigation event could be saved for alternatives 1 and 2 when not irrigating after 15/08. In fact, ASW is kept above the non-stress threshold until the end of the season for all three cases when the last irrigation is practiced before this date.

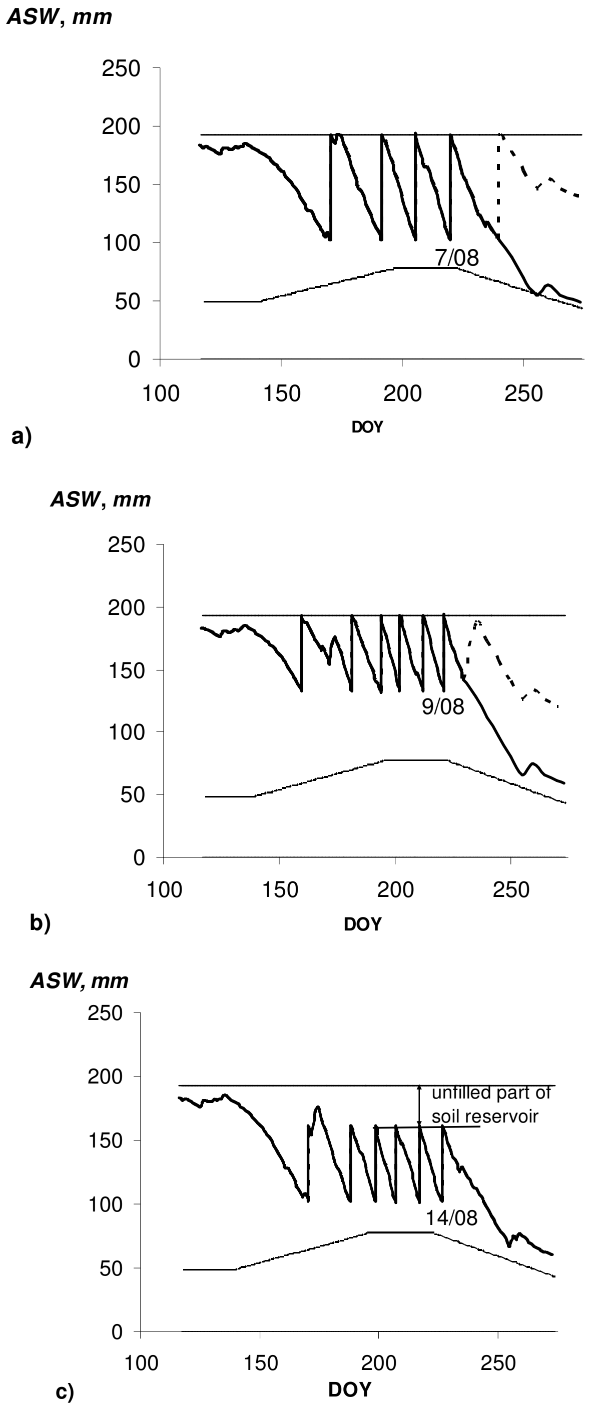
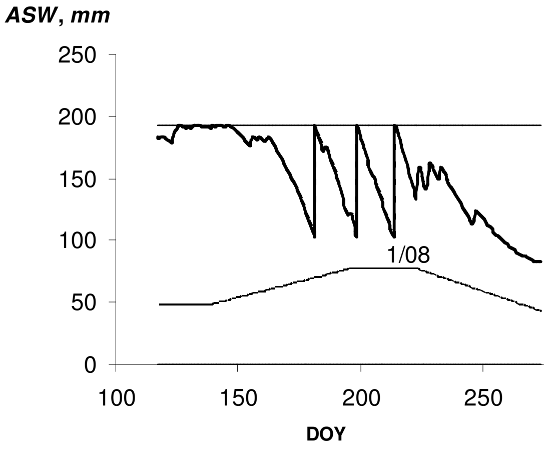
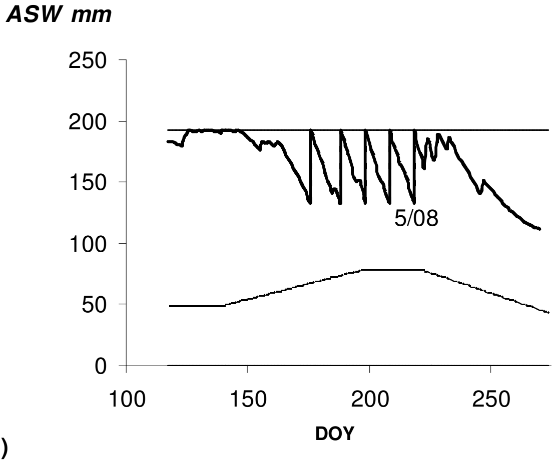


Fig. 19. Simulation of the available soils water (ASW, mm) for the three irrigation scheduling alternatives in the year of extreme irrigation demand (1981): a) alternative 1; b) alternative 2; and c) alternative 3, with identification of the date of the last irrigation. The horizontal line, above, corresponds to TAW and the broken line, below, to the non-stress threshold. (Vertisol, Pustren).

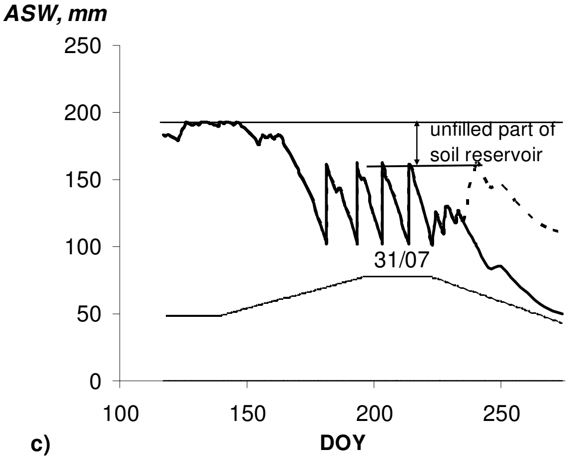
Results of ASW simulations of the 3 alternatives for 1980, the average demand year in the last 36 years, are shown in Fig. 20. Relative to the dry year (1981), the number of irrigation events reduces to 3, 5 and 4 for respectively the alternatives 1, 2 and 3; the last irrigation event is for all cases anticipated relative to the corresponding dates for the dry year. Hence, the irrigation demand reduces respectively to 270, 300 and 240 mm. These results agree with the analysis performed earlier when comparing NIR with the irrigation demand: alternative 3 produces the smallest demand and alternative 2 the highest, exceeding the former by 60 mm. For all 3 cases, ASW remains above the non-stress threshold when the last irrigation is applied before 15/08.



a)



b)



c)

Fig. 20. Simulation of the available soils water (ASW, mm) for the three irrigation scheduling alternatives in the year of average irrigation demand (1980): a) alternative 1; b) alternative 2; and c) alternative 3, with identification of the date of the last irrigation. The horizontal line above corresponds to TAW and the broken line below to the non-stress threshold (Vertisol, Pustren).

A summary of results for all alternatives including the rainfed one is presented in Table 17. For all irrigation alternatives, the actual evapotranspiration (ET_a) equals the potential crop ET (ET_c), thus no yield decrease is produced. Contrarily, for the rainfed crop $ET_a < ET_c$ originating high yield decreases, particularly when the water stress sensitive hybrid is considered. The rainfall is not fully used, particularly in the average year, because it falls during the earlier stages of the crop, when demand is low and the soil water content is high. The referred difference in water demand among the 3 alternatives in the average year is well visible through the ASW at harvesting: with alternative 3 it reduces to 50 mm while with alternative 2 a higher value of 110 mm is obtained. These results are coherent with the fact that alternative 3 allows a higher soil water depletion than alternative 2 (MAD = 0.47 *vs*. MAD = 0.33). Comparing alternatives 1 and 3, which have the same MAD, the higher ASW at harvesting and the corresponding higher irrigation demand for alternative 1 result from the fact that application depths for this one are larger than for the former (D = 90 mm *vs*. D = 60 mm).

Table 17. Summary water balance and yield decrease results of maize irrigation scheduling alternatives 1, 2 and 3 and rainfed alternative 4 for the average and the very dry years (Vertisol, Pustren)

Climate	Average year				Very dry year			
Year	1980				1981			
Precipitation May-Sep, mm	251				139			
Precipitation Jul-Aug, mm	92				63			
Net irrigation requirements, mm	234				348			
Irrigation alternatives	1	2	3	4	1	2	3	4
Irrigation depths, mm	270	300	240	0	360	360	360	0
Number of irrigation events	3	5	4	0	4	6	6	0
Crop evapotranspiration (ET_a)*, mm*	538	538	538	330	590	590	590	284
Non-used precipitation, mm	74	74	74	83	14	0	0	2
ASW at harvest, mm	82	110	50	18	49	59	60	15
Relative yield decrease when $K_y = 1$*, %*	0	0	0	40	0	0	0	55
Relative yield decrease when $K_y = 1.5$*, %*	0	0	0	58	0	0	0	80

The currently adopted irrigation scheduling in the Thrace (Zahariev *et al*. 1986) is different of the schedules evaluated above and generally exceed the irrigation demand herein proposed in moderately dry (P_I=25%) and average years (P_I=50%). The overestimation is 60 mm when compared with alternative 2, which adopts application depths similar to those proposed by Zahariev *et al*. (1986). Considering the currently proposed schedules, all 3 alternatives analysed above could lead to appreciable water savings in moderately dry to moderately wet years (75% > P_I > 25%), particularly alternative 3.

Alternative 3 could therefore be selected as the one producing higher water savings and good irrigation performances. It is easier to apply if surge flow is adopted because then advance times are shorter than for continuous flow. If the later is adopted, than furrows may have to be reduced to ensure adequate uniformity of distribution, particularly for the first irrigation. However, trials referred before (Popova *et al*., 1998; Popova and Kuncheva, 1996) show that net application depths of 60 mm can be applied with continuous flow and achieving good irrigation performances when soil moisture at time of irrigation is above the cracking threshold.

4.3 Yield impacts

The impacts on yields produced by the irrigation alternatives for both maize hybrids *Kn-2L-611* ($K_y = 1$) and *H708* ($K_y = 1.5$) are compared in Fig.20. Results indicate that for years when the adopted application depths do not fully cover the crop requirements (about 30% of the years) alternatives 1 and 3 produce an evapotranspiration deficit and therefore a yield decrease proportional to the yield response factor K_y that characterizes those hybrids. The relative yield decrease may attain a maximum of 16% in case of hybrid *H708* and 11% for hybrid *Kn-2L-611* with both alternatives 1 and 3. These alternatives have similar impacts on yields except for moderately wet years, which relates to the respective application depths. Yield decreases produced with alternative 2 are negligible in the practice.

According to these results, if irrigation is scheduled for maximizing yields without considering the need for improved water saving, the alternative 2 is the best. Further studies considering the economic impacts of water saving and yield decreases are then required to adequately base decisions. However, results show that a water stress sensitive maize hybrid such as H708 is less appropriate to be cultivated when irrigation is scheduled for water saving and water stress is allowed.

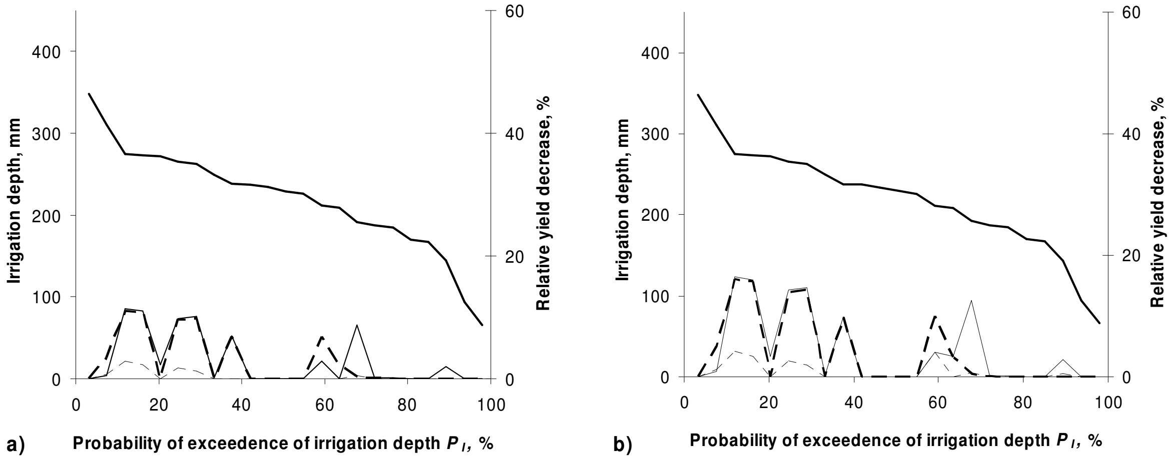


Fig. 20. Relative yield decrease for hybrids (a) *Kn-2L-611* ($K_y = 1$) and (b) *H708* ($K_y = 1.5$) in relation to the probability curve of net irrigation requirements (▬▬) and depending upon the adopted irrigation scheduling alternatives 1 (— —), 2 (·····) and 3 (—). Pustren, 1970-1992.

The relative yield decreases for both maize varieties referring to the rainfed crop (alternative 4) over the period 1970-1992 are plotted *vs*. the probability P_I of exceedance of net irrigation requirements (Fig. 21). Simulations relative to the drought resistant hybrid *Kn-2L-611* (K_y =

1) show that the relative yield decrease averages 21 % in wet years ($P_I > 75\%$), 47 % in dry years ($P_I < 25\%$) and 37 % in years of average demand ($40 < P_I < 60\%$). For the hybrid *H708* ($K_y = 1.5$), the relative yield decrease averages 30 % in wet years, 70 % in dry years and 50% for average demand years. These results indicate that the hybrid *H708,* as well as other hybrids highly sensitive to water stress, should not be cultivated under rainfed conditions; differently, the hybrid *Kn-2L-611* and other hybrids tolerant to water deficits would experience excessive yield decreases only in very dry years.

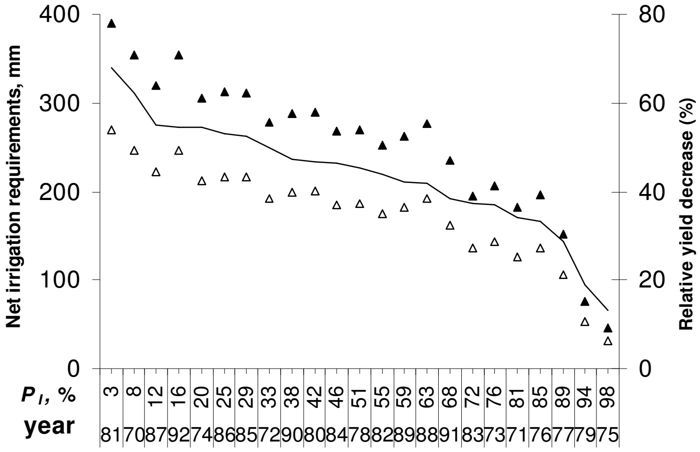


Fig. 21. Relative yield decrease of rainfed maize comparing the hybrids *Kn-2L-611* (Δ), with $K_y = 1$, and *H708* (▲), with $K_y = 1.5$, plotted against the NIR probability curve (—), 1970-1992

Simulations relative to Zora site lead to the following main results:

Net irrigation requirements at Zora are predominantly higher (by 35-55 mm) then those at Pustren. *NIRs* are practically equal in both soils only over the wettest seasons (P_I>80%). Compared to those relative to the chromic luvisol in Sofia field, *NIRs* at Zora are 80 mm larger over the average seasons (20%<P_I<70%);

The conventional time limit for irrigation **15/08** produces seasonal irrigation demands *IDs* less than *NIRs* and yield decrease upto 14% (schedule 3) and 29% (schedules 2 and 5). Thus the average yield decrease over the whole studied period ranges from 5.2% (alternative 3) to 7.5-9.7% (alternatives 2 and 5). Irrigation leads to maximum yield over all the years 1970-1992 when the last allowed irrigation date is extended to **31/08**; Thus irrigating till **15/08** is inappropriate in the chromic cambisol soils, Stara Zagora.

Adopting 15/08 as time limit for irrigation produces seasonal IDs smaller than NIRs (Fig.22b) and yield decreases up to 14% (schedule 2) and 29% (schedules 1 and 3). The average yield decrease over the whole studied period ranges from 5.2% (alternative 2) to 7.5-9.7% (alternatives 1 and 3). Irrigation leads to maximum yield over all the years 1970-1992 when the last allowed irrigation date is extended to 31/08. Thus irrigating till the conventional time limit 15/08 is inappropriate in the chromic cambisol soils, Stara Zagora.

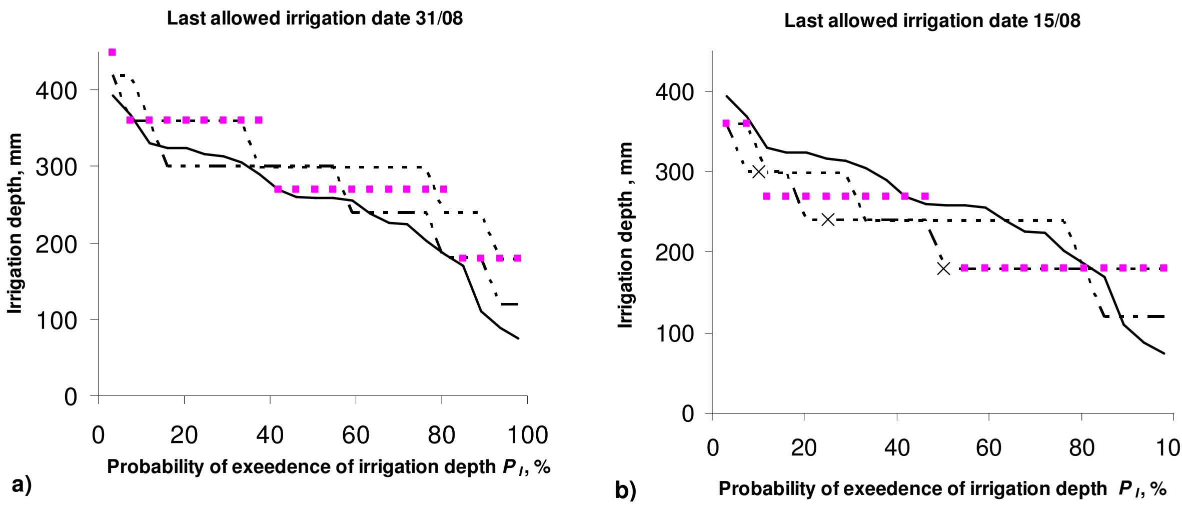


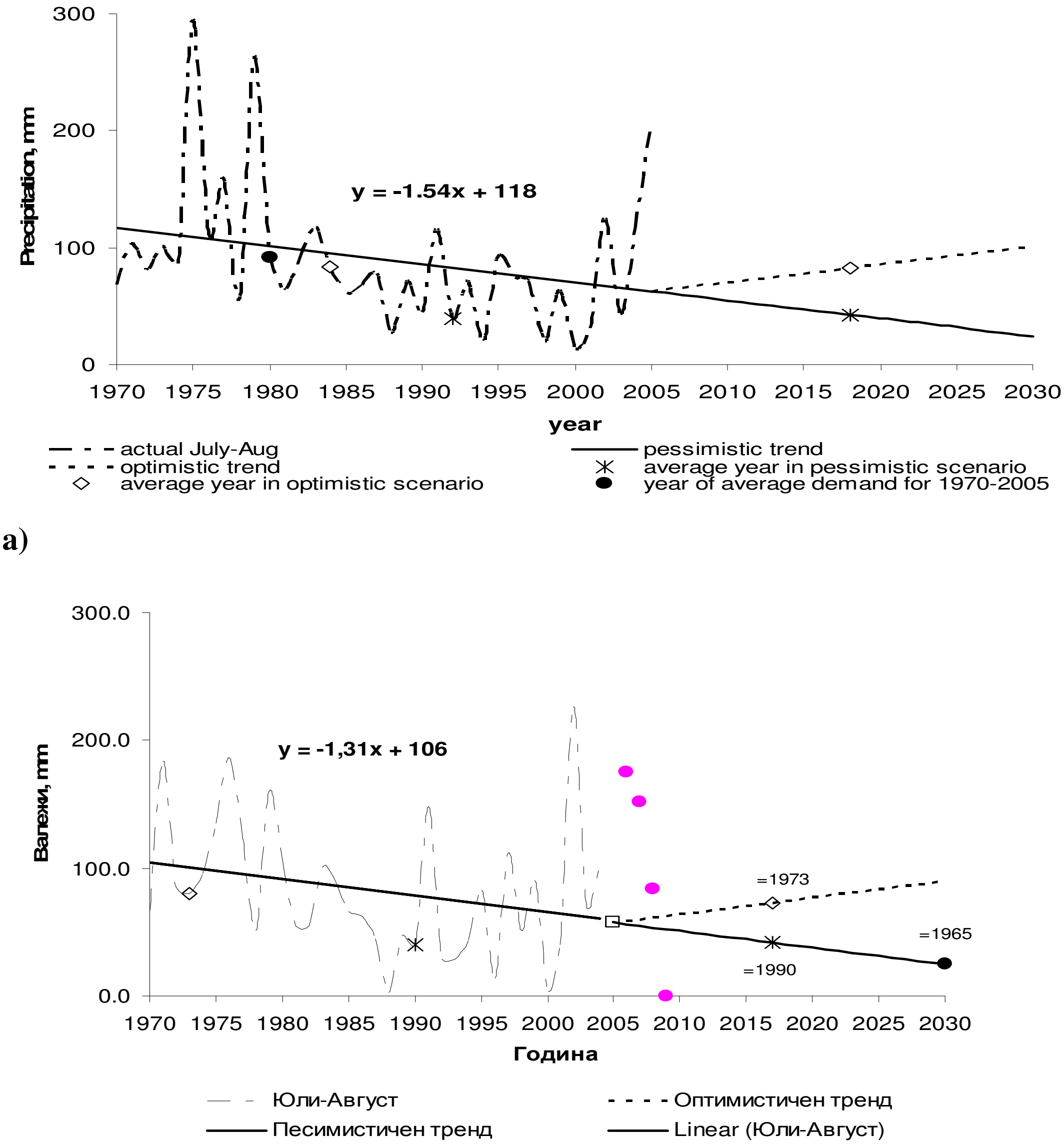
Figure 22. Probability curves of net irrigation requirements, NIRs (—), and net season irrigation demands, IDs for the irrigation scheduling alternatives 1 (■), 2 (·····) and 3 (·· — ··), compared to IDs for currently adopted scheduling of Zahariev et al., 1986 (x) when the last allowed irrigation date is: a) 31/08 and b) 15/08. Zora, 1970-1992

Results of simulations are compared with irrigation schedules presently advised in the region (Zahariev et al., 1986) and show that the later do not fully cover crop irrigation requirements *NIRs* in some seasons when yield decrease occurs.

In terms of drained precipitation extremes, risky years are two – those of lowest *NIRs* **1980** (P_I=94%) and **1975** (P_I=98) (Table 17).

4.4 Scenarios of climate change

Uncertainty in precipitation is considered through building a pessimistic and an optimistic scenario. The first builds upon the assumption that the trend of precipitation decrease in July and August would be the same as for the last 36 years (1970-2005). It is therefore built by extending for the following 25 years the same “trend” as for 1970-2005 (full line in Fig. 23).



a)

b)

Figure 23. Cumulative rainfall in July and August over the last 36 years (1970-2005) and scenarios for precipitation trends for the period 2005-2030 with identification of the average years in pessimistic and optimistic scenarios, Pustren site, Stara Zagora- a) and Tsalapitsa site - b).

The seasonal rainfall (May-September) at Pustren site would then reduce by 50 mm until 2030, while during July-August the rainfall decrease would be 37 mm (Fig.23). At Zora site those decreases arerespectively 69 and 45 mm. The optimistic scenario assumes a reversing trend for that period 2005-30, thus an increase of the precipitation of 37mm and 45 mm at both sites during July and August. These scenarios do not result from predictions but are just built to assess possible consequences of climate variations on the maize irrigation demand and to check how the considered irrigation scheduling alternatives would behave in case rainfall conditions during July-August would or not decrease.

4.5 Irrigation under the optimistic weather scenario

To assess how future climate scenarios could affect irrigated agriculture, irrigation scheduling simulations are performed for **optimistic and pessimistic scenarios weather conditions**. Results show that irrigation scheduling alternatives 1, 2 and 3 can easily accommodate the foreseen changes mainly by adequately selecting the irrigation dates as shown in figures 24, 25,2 6 and 27, and tables 18 and 19. For the average demand year of the **pessimistic scenario** of precipitation decrease it is observed that the last irrigation should be applied after the conventional date (15/08) – on 31/08 in vertisols and on 1-9/09 in chromic cambisols respectively (fig.24). Results of simulations do not allow selecting one among the studied alternatives as the best irrigation scheduling strategy but are useful to later building an information system for farmers using actual weather data. Yield impacts highly increase for the pessimistic scenario, particularly for the water stress sensitive hybrid *H708*. Results indicate that vulnerability to climate change is higher for non-irrigated crops. Considering the average demand year future precipitation decrease would lead to **20%** less yield production in vertisols and respectively **27%** less in chromic cambisols. Coping with possible rainfall decreases requires adopting less sensitive crop hybrids, including when deficit irrigation would be applied for water saving.

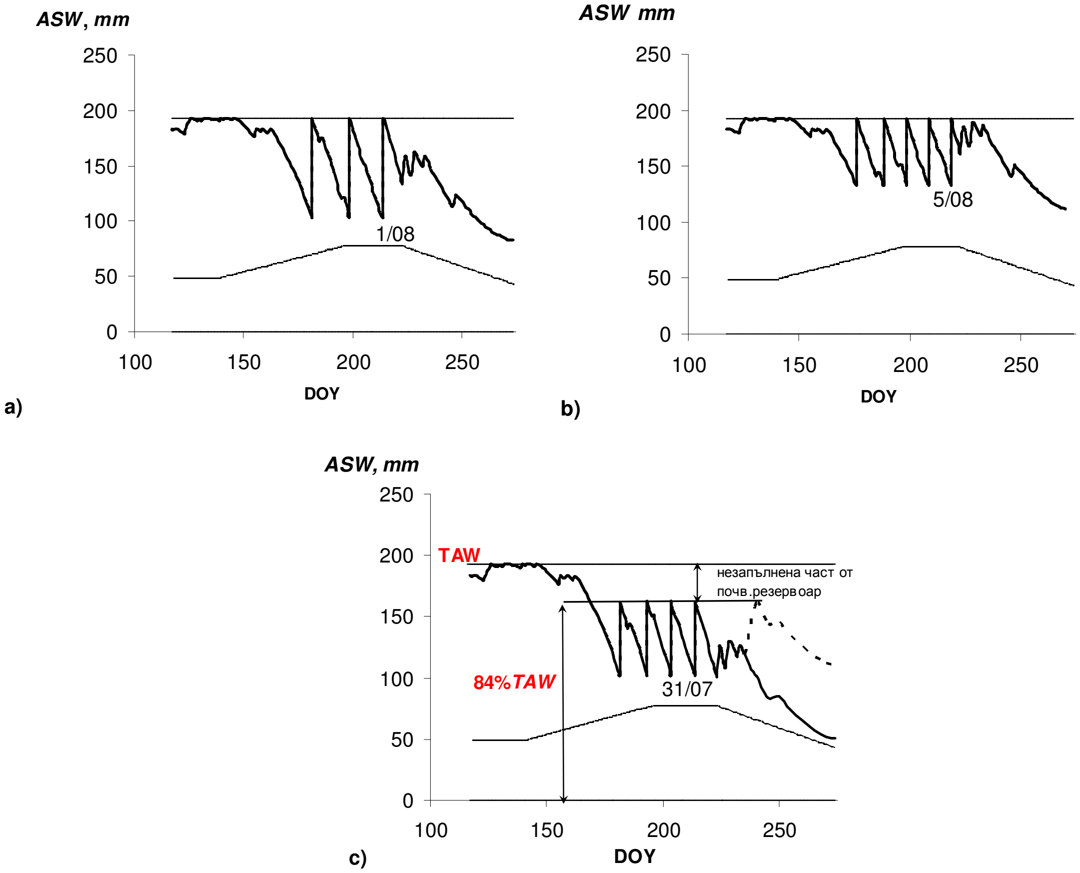


Figure.24. Simulation of the available soil water (ASW, mm) for three irrigation scheduling alternatives in the *year of average irrigation demand* of the **optimistic scenario**: a) alternative 1; b) alternative 2; and c) alternative 3, with identification of the date of the last irrigation date at **Pustren** site. The full line represents simulation results when the last irrigation is to be applied before 15/08 and the dashed line when that limit is 31/08. The horizontal line above corresponds to TAW and the broken line below to the non-stress threshold.

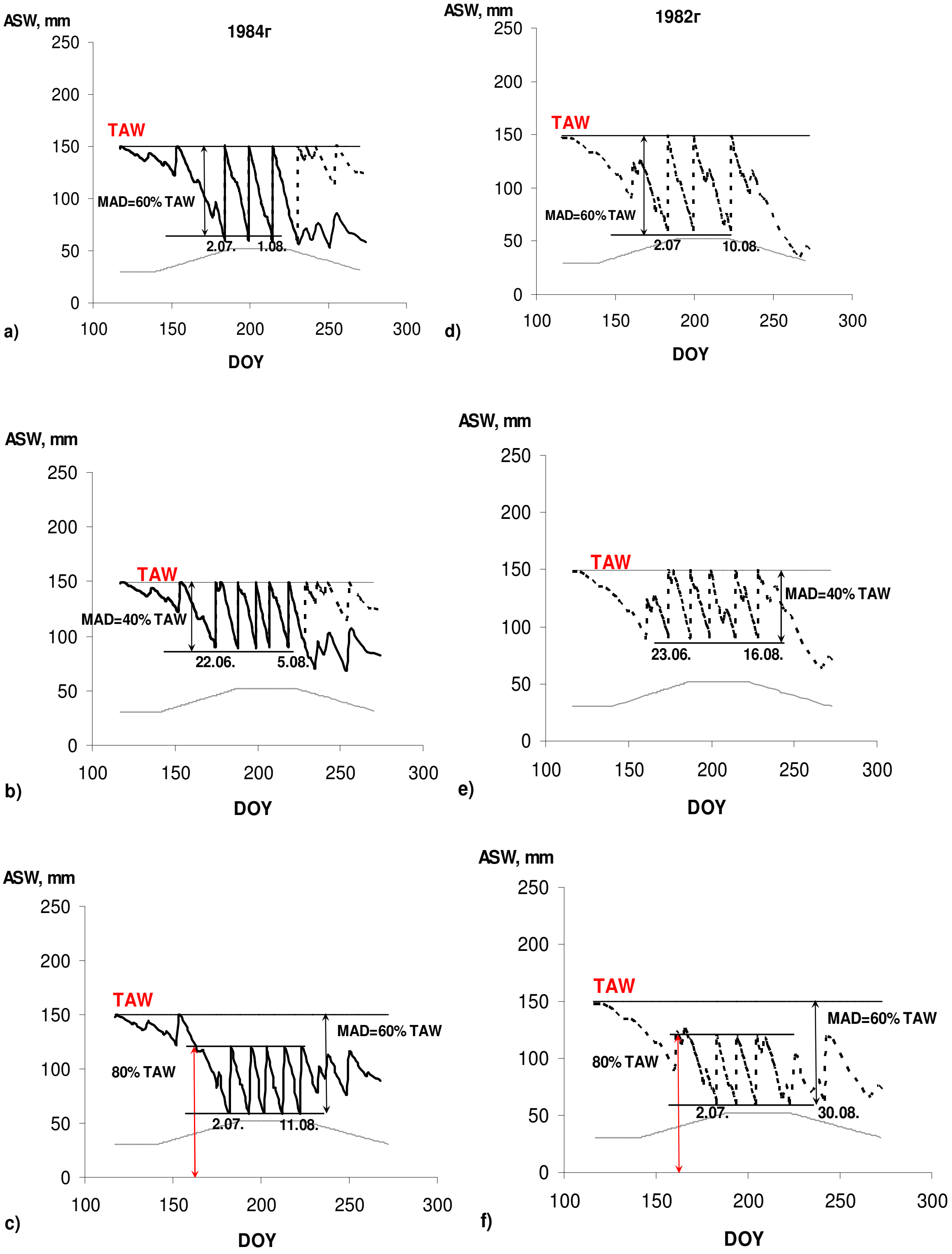


Figure.25. Simulation of ASW (mm) for three irrigation scheduling alternatives in *two years of average irrigation demand* - 1984 (a - c) and 1982 (d - e) - for the **optimistic scenario at Zora** site: a) and d) alternative1; b) and e) alternative 2; c) and f) alternative 3, with identification of the date of last irrigation. The full line represents simulation results relative to the last irrigation by 15/08 and the dashed line for the last irrigation by 31/08. The horizontal line above corresponds to TAW and the broken line below to the non-stress threshold.

Table 18. Summary water balance and yield decrease results of maize irrigation scheduling alternatives 1, 2 and 3 and rainfed alternative 4 for the average years of the pessimistic and optimistic scenarios at Pustren field for 2005-2030.

	Pessimistic scenario				**Optimistic scenario**			
Representative years	1992				1984			
Precipitation May-Sept, mm	177				237			
Precipitation Jul-Aug, mm	40				83			
Net Irrigation Requirements, mm	273				238			
Irrigation alternatives	1	2	3	rainfed	1	2	3	rainfed
Season irrigation depths, mm	270	300	300	0	270	300	240	0
Number of irrigation events	3	5	5	0	3	5	4	0
Crop evapotranspiration (ET_a), mm	557	557	557	310	548	548	548	354
Non-used rainfall, mm	32	32	32	42	0	0	0	0
ASW at harvesting, mm	42	69	70	3	118	138	146	47
Relative yield decrease, K_y =1 %	0	0	0	50	0	0	0	37
Relative yield decrease, K_y = 1.5 %	0	0	0	70	0	0	0	53

Table 19. Simulation of three irrigation scheduling alternatives aiming at maximum yield (1, 2 and 3) and crop without irrigation for the average demand year of the **pessimistic** and **optimistic scenarios** of precipitation change in the period **2006-2030**, **Zora** site, Stara Zagora

Average year for												
	Pessimistic scenario				**Optimistic scenario**							
Year (P_I)	1992 (20%)				1984 (51%)				1982 (42%)			
Seasonal precipitation (mm)	243				264				270			
Precipitation July-Aug (mm)	40				62				168			
Net Irrigation Requirements,(mm)	**324**				**259**				**264**			
Irrigation scheduling alternatives	1	2	3	rainfed	1	2	3	rainfed	1	2	3	rainfed
Irrigation demands, **IDs** (mm)	360	360	**360**	0	270	300	**300**	0	270	300	**300**	0
Irrigations number	4	6	6	3	3	5	5	0	3	5	5	0
Date of first irrigation event	19/07	14/07	19/07		2/07	22/06	2/07		2/07	23/06	2/07	
Date of last irrigation event	**1/09**	1/09	**9/09**		**1/08**	5/08	**11/08**		10/08	16/08	30/08	
Nonused precipitation (mm)	**41**	41	41	4	5	**12**	12	6	**0**	2	0	1
ASW at harvesting (mm)	66	66	67	1	59	83	90	34	42	70	73	17
Yield decrease (%), Ky=1.5	0	0	0	**83**	0	0	0	**64**	0	0	0	**62**

4.6 Irrigation under a pessimistic weather scenario

To assess how future pessimistic climate scenario could affect irrigated agriculture, irrigation scheduling simulations are performed for the weather conditions in 1992, when the precipitation in July and August is similar to that of the average demand year in the pessimistic scenario (Fig.26). Results show that irrigation scheduling alternatives 1, 2 and 3 can easily accommodate the foreseen changes mainly by adequately selecting the irrigation dates as shown in Figures 26 and 27.

For the average irrigation demand year and the pessimistic scenario of precipitation decrease it is observed that the last irrigation should be scheduled after the conventional date (15/08), by 19 to 28/08 in vertisols (Fig.26) and by 1 to 9/09 in chromic cambisols respectively (Fig.27). Compared with present weather conditions, seasonal irrigation demands, IDs, would rise by 60 mm in case of the irrigation scheduling alternative 3 only at Pustren field (a vertisol) and by 60-90 mm for all irrigation alternatives at Zora site (a chromic cambisol).

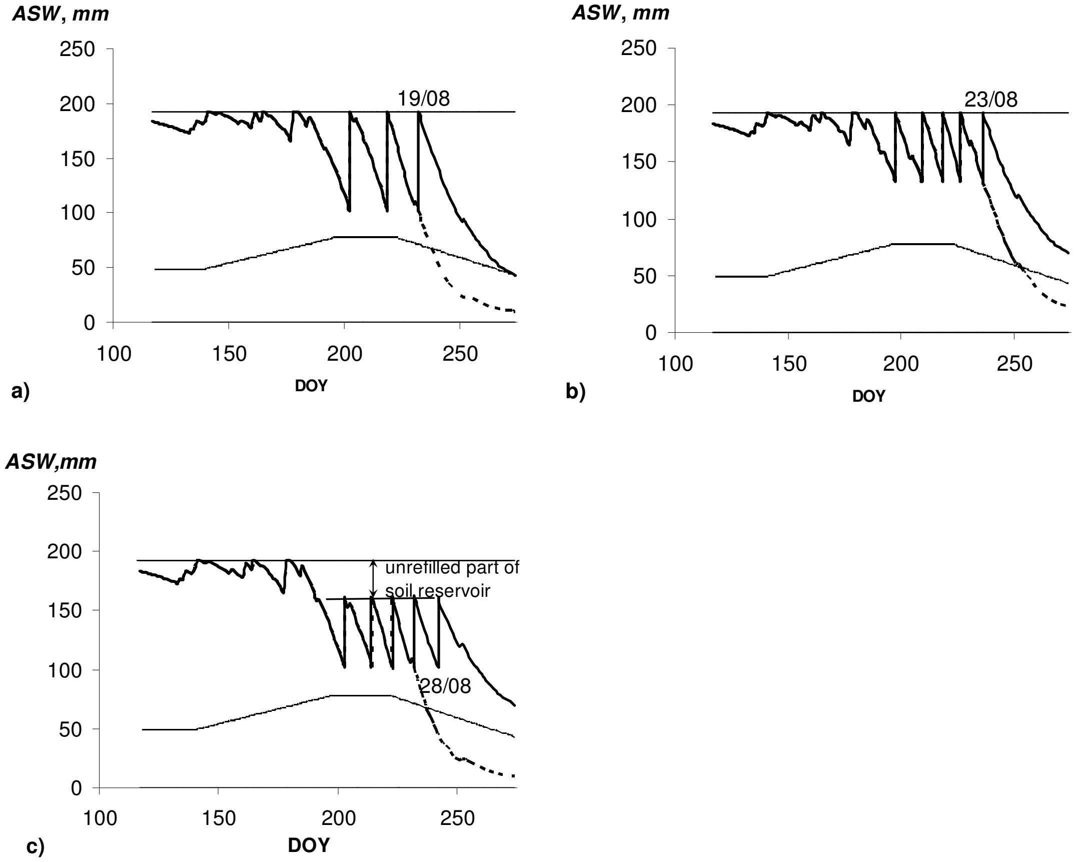


Figure.26. Simulation of ASW, mm for three irrigation scheduling alternatives in the *average demand year* of **the pessimistic scenario** (1992): a) alternative 1; b) alternative 2; and c) alternative 3, with identification of the date of the last irrigation, **Pustren** site.

The full line represents simulation results relative to non-stress conditions and the dashed line those when the last irrigation is by 31/08. The horizontal line above corresponds to TAW and the broken line below to the non-stress threshold.

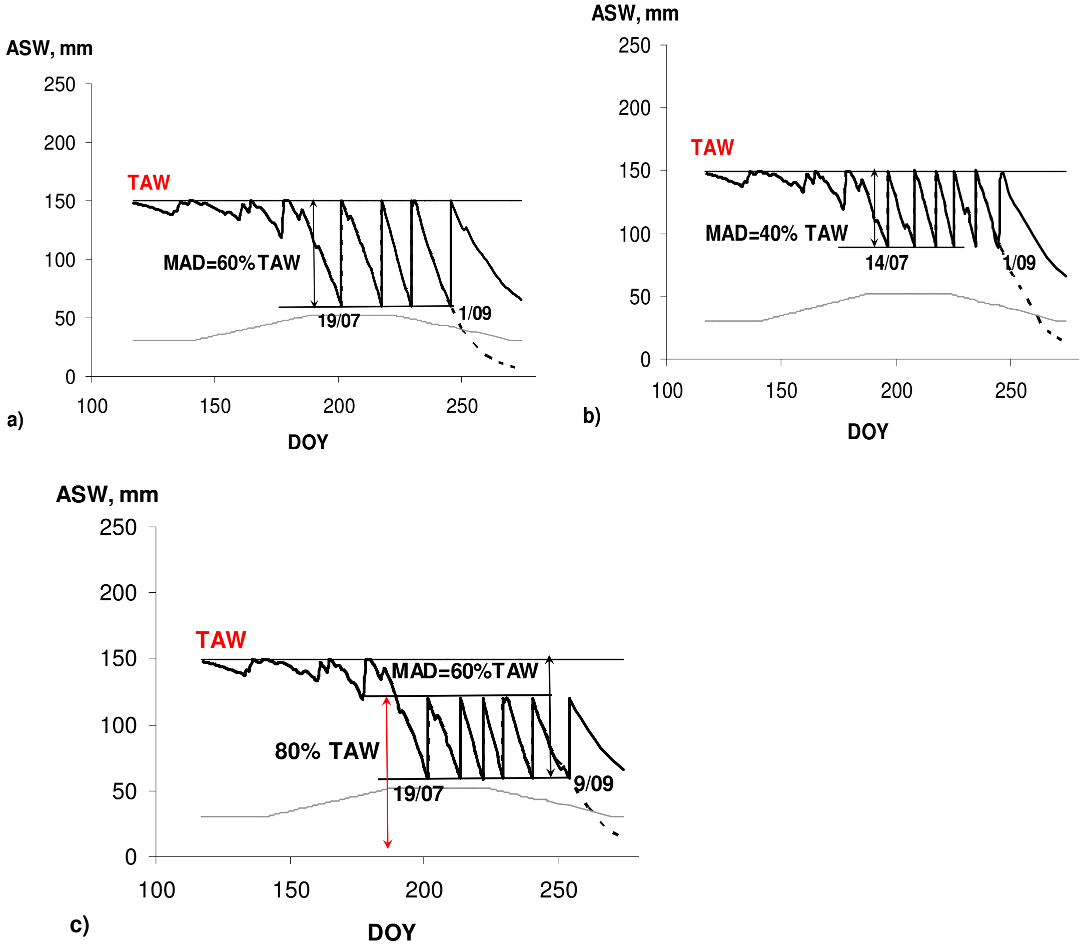


Figure.27. Simulation of ASW, mm for three irrigation scheduling alternatives in the *average demand year* of **the pessimistic scenario** (1992): a) alternative 1; b) alternative 2; and c) alternative 3, with identification of the date of the last irrigation, **Zora** site. The full line represents simulation results relative to non-stress conditions and the dashed line those when the last irrigation is by 31/08. The horizontal line above corresponds to TAW and the broken line below to the non-stress threshold.

Results of simulations do not allow selecting one among the studied alternatives as the best irrigation scheduling strategy but are useful to later building an information system for farmers using actual weather data. The conventional time limit for the last irrigation (15/08) highly increases yield impacts for the pessimistic scenario, particularly for the water stress sensitive hybrid H708. Results indicate that vulnerability to climate change is higher for maize when cropped in a chromic cambisol. Coping with possible rainfall decreases requires adopting less sensitive crop hybrids, when deficit irrigation would be applied for water saving.

5 CONCLUSIONS

The calibration and validation of the ISAREG model using historic long term experimental data on maize cropped in a soil of small (116 mm^{-}1), medium (136 mm^{-}1) and large (173 and 180 mm^{-1}) water holding capacity under dry climate and various irrigation and rainfed regimes has been successfully performed. Calibration was performed using soil water content observations and validation was performed with soil moisture data and season actual evapotranspiration. The accuracy of the calibrated model was tested against experimental data (1972-1990) from all irrigation and rainfed treatments by comparing the computed *versus* observed seasonal evapotranspiration. Results relative to Pustren and Tsalapitsa and the period 1981-1990 show a regression slope 1.05 and 0.94 and an AAE = 36-38 mm per season, which is less then 8% of the average evapotranspiration observed. Statistical tests relative to the "very dry" years (1988-1990) show a regression slope practically equal to 1 and a very small AAE = 9.9 mm per season.

The calibrated crop coefficients K_c are similar for all locations in the Thracian Plain but dates and duration of crop growth stages are different. These results confirm that when properly estimated considering local climate influences, the K_c values have a quite small variation; conversely, dates and duration of crop growth stages can not be imported from other locations without appropriate observations. However, overall, the results for modelling efficiency and the index of agreement are high indicating a good performance of the model. The derived depletion fraction for no stress p show to be dependent on the irrigation management adopted. Thus, they may vary from a location to another and with the irrigation method.

Assessing the yield water factor K_y =1.32 derived from experimental data has shown important to understand possible sources of underestimation of the relative yield decrease. In this study, this decrease relates with the variability of experimental data relative to 7 years and various irrigation treatments. However, the K_y derived looks appropriate for using with the model to assess yield impacts of water stress due to irrigation scheduling options. It may also be concluded that the derivation of K_y from treatments not having a relative yield deficit higher than 0.5 revealed important since feasible irrigation calendars generally do not admit higher water stress.

It can therefore be concluded that the methodologies used for calibrating, validating and testing the model using historic field data were appropriate and the results obtained support the use of the model for developing improved irrigation practices in the Plovdiv region, South Middle Bulgaria.

To assess how future climate scenarios could affect irrigated agriculture, irrigation scheduling simulations were performed in two soils of contrastive hydraulic properties and for two maize hybrids with different sensitivity to water stress. Various irrigation scheduling alternatives were compared in terms of seasonal irrigation demands and yield impacts under different precipitation scenarios**. For present climate**, net irrigation requirements vary widely, from less than 100 mm in wet crop seasons up to 350 mm (vertisols) and 400 mm (chromic cambisols) in dry years. Simulations for the very dry year have shown that all alternative irrigation schedules behave similarly when non-stress conditions are aimed at. For the average year, the alternatives allowing a larger soil water depletion (MAD = 0.47-0.60) require less water than the one having a MAD = 0.32-0.40. The lowest demand corresponds to alternative 3 that adopts smaller irrigation depths and refills the soil reservoir 30 mm below the total available water to better store any rain falling during the season. However, the analysis of impacts on yields from simulations relative to every year during 1970-1992 shows that alternative 3 leads to less impacts on yields. Results indicate also that the currently advised last irrigation by 15/08 is inappropriate in chromic cambisols when non-stress conditions are aimed at.

For the average demand year of the **pessimistic scenario**, it is observed that the last irrigation should be applied after the conventional date (15/08). The available soil water at harvest is then reduced and an additional irrigation is required for alternative 3 in vertisols and for all three alternatives in chromic cambisols. For the **optimistic scenario**, simulation results are similar to those for the average demand year of present climate. Therefore, results show that all irrigation scheduling alternatives can easily accommodate the foreseen changes. However, none of the alternatives may be selected as the best irrigation scheduling strategy despite alternatives from 1 to 3 respond well to constraints of the furrow irrigation method in cracking vertisols and adapt well to present and future scenario conditions. The question is to create an information system for farmers that help them to better scheduling irrigations, hopefully with support of a simulation model, as the one adopted in this study, and actual weather data. Building such an information system is a next challenge to help coping with climate uncertainties. Considering alternative maize varieties and alternative crops is also foreseen.

Results indicate that vulnerability to climate change is higher for soils of less water holding capacity and more sensitive crop varieties. Coping with possible rainfall decreases requires adopting less sensitive maize hybrids, mainly if deficit irrigation for water saving is applied.

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