DOI: 10.2478/ahr-2021-0001

Acta Horticulturae et Regiotecturae – Special Issue
Nitra, Slovaca Universitas Agriculturae Nitriae, 2021, pp. 1–7

IRRIGATION SCHEDULING OF MAIZE GROWN ON A VERTISOL SOIL UNDER CHANGING CLIMATE OF SOFIA'S FIELD

Maria IVANOVA*, Zornitsa POPOVA

Institute of Soil Science, Agrotechnology and Plant Protection "N. Poushkarov", Sofia, Bulgaria

The purpose of this study is to evaluate the impact of climate uncertainties on maize irrigation requirements, grown on a Vertisol soil, Sofia's field, Bulgaria. Through the validated WinIsareg model, four irrigation scheduling alternatives are simulated for the years of "very high", "high" and "average" irrigation demands of past (1952–1984) and present (1970–2004) climate. Adaptation of irrigation scheduling to the present climate conditions during the "very dry" years ($P_I \leq 12\%$) consists of an extension of the irrigation season by 15–20 days and a need of additional irrigation relative to alternative 1 and two irrigation events at alternatives 2 and 3. During the past climate alternatives 2 and 3 led to savings of 30 mm of water, while up to the current climate conditions the three irrigations alternatives should provide 360 mm of irrigation water. To obtain maximum yields in "dry" ($P_I = 12–30\%$) years, irrigation season should end by 05/09, as in the present climate, irrigation season has shifted about a week earlier for the three alternatives. In the "average" ($P_I = 30–60\%$) years the adaptation consist in accurately determination of the last allowed date for irrigation.

Keywords: irrigation scheduling, maize, climate change, water management, yield

Irrigation scheduling is crucial for the efficient management of water resources consumption and for optimizing the yield of irrigated areas. Net Irrigation Requirements (NIRs) of the crops are mainly characterized by climatic conditions in an agricultural area.

Sofia's field is characterized by moderate continental climate and is one of the wettest and coolest agricultural regions of Bulgaria. However, there has been found a trend of decreasing precipitation by 2.7 mm per year and increasing reference evapotranspiration (ETo) by 1.0 mm per year during the growing (May – September) season of the present climate conditions 1970–2004 (Figure 1a and 1b).

Regarding the irrigation season, similar trends of decrease in precipitation by 2.61 mm per year and increase the ETo by 0.86 mm per year have been identified under the present climatic conditions (1970–2004) (Popova, Ivanova,

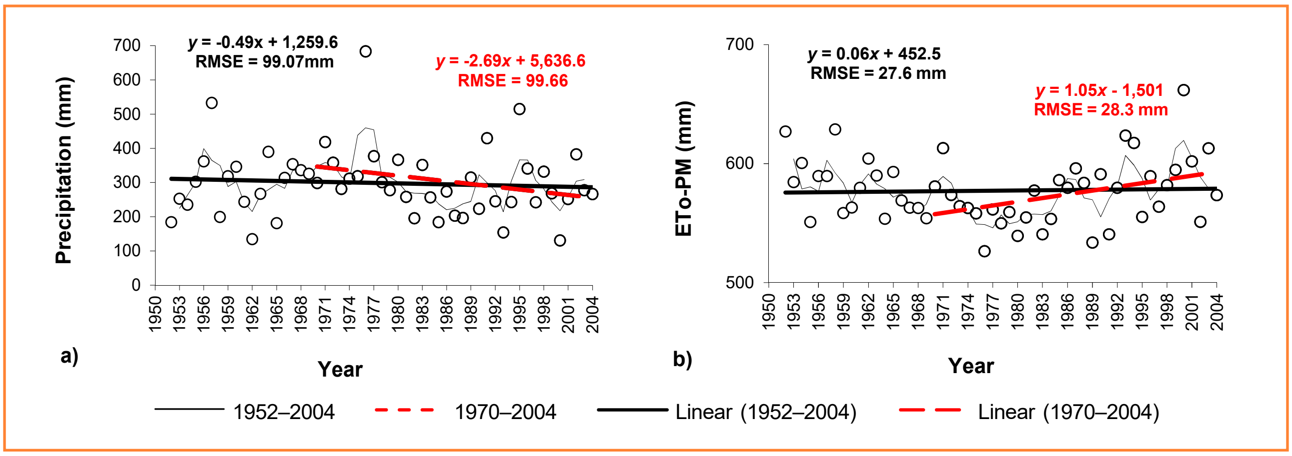

Figure 1 a) Precipitation and b) reference evapotranspiration by Penman-Monteith equation (ETo – PM) during the growing (1/05–30/09) period of maize, Sofia, 1952–2004
—— average for 3years; ▬ trend for 1952–2004; – – trend for 1970–2004

Contact address: Maria Ivanova, Institute of Soil Science, Agrotechnology and Plant Protection "N. Poushkarov", Department of Physics, Erosion, Soil Biota; 7, Shosse Bankya str., Sofia 1331, Bulgaria, ☎ +35 98 78 90 95 76, e-mail: mulykostova@abv.bg

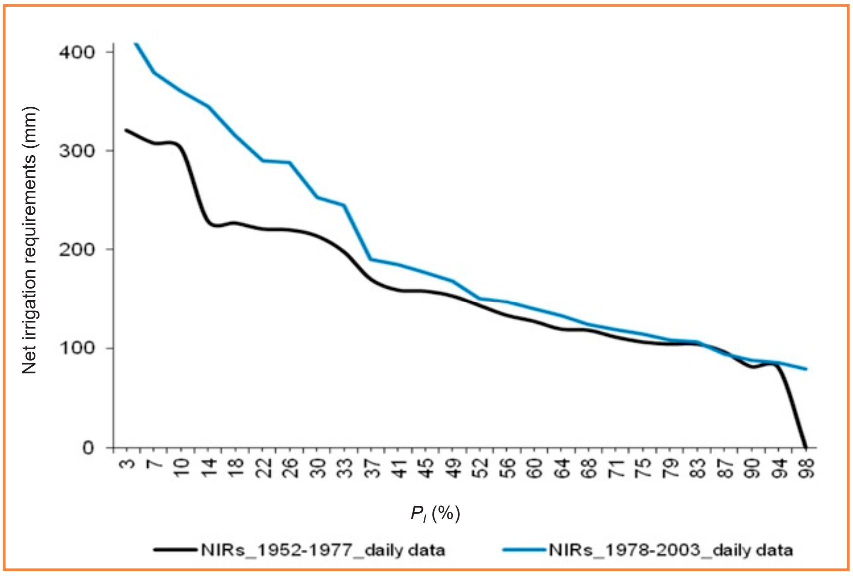

Figure 2 Comparison of probability of occurrence curves of a Net Irrigation Requirements, NIR (mm) of maize, computed with all required daily climate data during the past 1952–1977 and present 1978–2003 climate conditions, Sofia's field

Alexandrov, Doneva, 2014a; Popova, Ivanova, Martins, Pereira, Doneva, Alexandrov, Kercheva, 2014b; Popova, Ivanova, Pereira, Alexandrov, Kercheva, Doneva, Martins, 2015). The identical percentages of rainfall decreases and ETo increases during the growing and the irrigation season show that the trend is mainly due to the changes in climatic conditions during the irrigation season "June – August".

The defined trends inevitably lead to changes in NIRs. Figure 2 compares the NIRs, mm, for the past (1952–1977) and present (1978–2003) climate conditions. The impact of climate change is seen to be greatest during the very high irrigation demand years with a protbability of occurrence $P_l \leq 12\%$ and the high irrigation demand (P_l = 12–30%) years, when NIRs increased by 60–115 mm and 40–100 mm, respectively. During the average years (P_l = 30–65%) NIRs increased by 10 to 40 mm.

Under the changes in climatic conditions established by us and other authors (Alexandrov, 2011; Slavov, Koleva, Alexandrov, 2003; Koleva, Alexandrov, 2008; Popova et al., 2014a, b), the published irrigation scheduling (Zahariev, Lazarov, Koleva, Gaidarova, Koichev, 1986) should be reviewed and updated, as well as include scheduling with different irrigation rate and with different degree of water depletion in soil.

The purpose of this study is to develop irrigation scheduling for the rational irrigation of Vertisol soil grown maize, appropriate for the present climatic conditions in Sofia's field and to determine the effects of drought on irrigation rates and yields of semi-early and late maize hybrids for past (1952–1984) and present (1952–2004/1970–2004) weather. For this purpose, a validated simulation model of soil water balance, irrigation scheduling and the effects of water stress on yields WinISAREG (Teixeira, Pereira, 1992; Pereira, Teodoro, Rodrigues, Teixeira, 2003) was used, with soil and crop parameters adapted to the local conditions (Ivanova, Popova, 2012).

Material and method

For the calculation of evapotranspiration (ET) and NIRs of maize, a simulation model of irrigation scheduling and soil water balance WinISAREG (Pereira et al., 2003) was applied. ETo was calculated using the updated methodology proposed by Allen, Pereira, Raes, Smith (1998).

Data on soil texture and hydraulics are used to define the Total Available Water in the root zone of 1 m of TAW = 180 mm.m^{-1} (Table 1).

The previously validated crop parameters, as described by Ivanova, Popova (2012) have been presently used after respective adaptation to local climate and soil conditions (Table 2).

The WinISAREG model was also applied to compare simulated irrigation scheduling alternatives under different levels of soil moisture before irrigation and irrigation rates and for assessment of their impact on yields. The research aims to develop environment friendly

Table 1 Main soil physical and hydraulic properties of a Vertisol soil at Bojourishte experimental field of Sofia's field

Experimental field	**Horizon**	**Depth (cm)**	**Soil particles in mm (%) (FAO system classification)**			**Ksat (cm day^{-1})**
			clay <0.002 mm	**silt 0.002–0.05 mm**	**sand 0.05–2.00 mm**	
Bojurishte	A_1	0–45	54	33	13	0.63
	A_2B_1	45–100	63	27	10	0.63

Table 2 Dates limiting crop development stages and modeling parameters: crop coefficients *Kc* and depletion fraction for no stress *p*, Vertisol soil, Bojurishte experimental field, Sofia, 2004

Growth phases/Dates	**Initial period/05/05 to 06/06**	**Mid-season/01/08 to 01/09**	**End-season/20/10**
Kc	0.40	1.28	0.6
p	0.46–0.75	0.6	0.78

and water savings oriented alternatives to prevent soil cracking maintaining soil moisture levels above 80% FC, irregularity in water distribution, and water and yield losses. The Alternative 1 assumes a degree of Management Allowed soil water Depletion MAD = 0.50, i.e. up to 82% of Field Capacity (FC), and an irrigation rate of 90 mm, measured experimentally in continuous furrow irrigation (Figure 4a); the Alternative 2 deals with the case of replenishment of the soil reservoir to 88% of FC corresponding to MAD = 0.33, and irrigation rates of 60 mm, applied for impulse irrigation in order to reduce the lacking uniformity of water distribution and irrigation rate (Figure 4b); the Alternative 3 aims to better retain and use rainfall and irrigation water with a sprinkler irrigation. It consists of replenishing the soil reservoir up to 82% of TAW, adopting MAD = 0.50 and irrigation rates of 60 mm. About 30 mm from the soil reservoir remain unfilled in order to accumulate any precipitation after the irrigation has been applied (Figure 4c); the Alternative 4 is the option "crop without irrigation". According to the regional irrigation practice published by Zahariev et al. (1986), the last allowed irrigation date is 21/08 for an average and a high irrigation demand years, having probability of exceedance of irrigation rate $P_I = 50\%$ and $P_I = 25\%$ and 31/08 for the year of very high irrigation demand ($P_I = 10\%$).

Irrigation simulations are performed with a complete set of daily data including maximum and minimum air temperature T_{max} and T_{min}, average daily relative humidity RH, wind speed WS at 2 m altitude and precipitation P for the period 1952–2007 (data from Meteorological Years journals 1952–1980, Meteorological Months journals 1981–1984 and National Institute of Meteorology and Hydrology 1984–2007). The total solar radiation RS is calculated by the temperature difference method, which is based on the fact that the difference between the maximum and minimum temperatures gives the closest estimate of the actual RS in the area (Ivanova, Popova, 2011). The coefficient of proportionality Krs = 0.16 was found to be the most suitable for the Sofia's field (Ivanova, Popova, 2011).

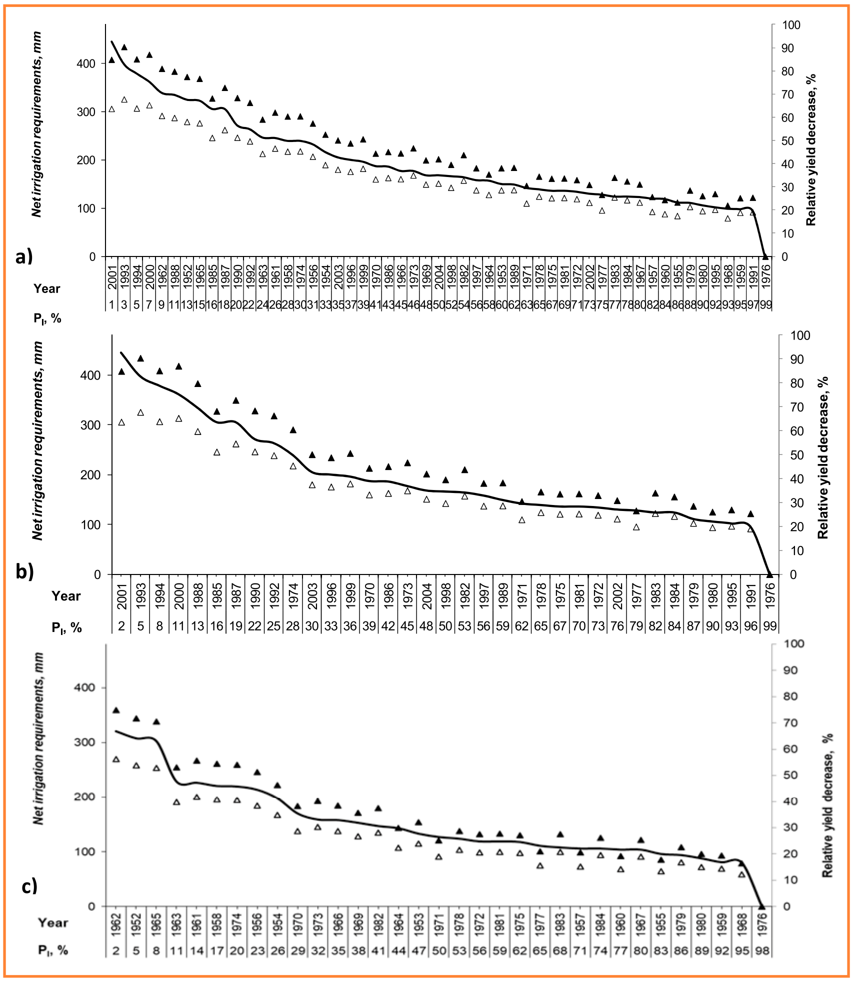

Figure 3 Probability curves of Net Irrigation Requirements, NIR, mm (—) and Relative Yield Decrease of rainfed maize, RYD,%, comparing the semi-early P37-37 (Δ), Ky = 1.2, and late H708 (▲), Ky = 1.6, maize hybrids, computed with all required daily data relative to three periods: a) 1952–2004; b) 1970–2004 and c) 1952–1984

Results and discussion

Yields and irrigation requirements in changing climate

Monthly precipitation and ETo series (1952–2004), computed as described by Ivanova, Popova (2011), have been used to build probability curves of occurrence of NIRs and corresponding Relative Yield Decrease RYD related to rainfed maize semi-early and late hybrids (Figure 3).

Comparing the years with different probability of exceedance of the hole studied 1952–2004 and the present 1970–2004 periods it can be seen that very high irrigation demand years (2001, 1993, 1994, 2000, 1988, 1985) with the probability of NIRs P_I <16%, high irrigation demand (1987, 1990, 1992, 1974, 2003) with P_I = 20–40%, the average (1973, 2004, 1998) with P_I = 40–60%, the medium-wet with P_I = 60–75% and the wet (P_I ≥80%) years have identical supply of NIRs in the two periods (Figs 3a and 3b). Therefore, the irrigation rates required and the relative losses of rainfed maize yield are practically the same over the two periods.

However, comparing the period of the past climate 1952–1984 and the long series of 53 years (1952–2004), it can be seen that the probability of exceedance of NIRs decreased from 9% to 2% in the extremely dry 1962 year, from 30% to 20% in the average dry 1974, from 46% to 35% in the average 1973 (Figs 3a and 3c). These changes reflect present climatic conditions, which show that the onset of drought leads to an increase in the required

NIRs and yield losses of rainfed maize (Figs 3b and 3c).

Figs 3b and 3c also show the simulated net irrigation rates and the corresponding relative losses of non-irrigated maize yield, calculated with a complete set of required meteorological data for the years 1952–1984 and 1970–2001. It can be seen that only during the wettest year ($P_I = 98\%$) there is no need for irrigation and consequently loss of yield. During the current climate 1970–2004, the NIRs is higher by about: 20–30 mm in wet years ($P_I = 65–95\%$), 20–35 mm in average ($P_I = 30–65\%$), 45–100 mm in the dry ($P_I = 12–30\%$) and 100–120 mm during the driest ($P_I < 8\%$) years.

Due to the water stress, RYD, in the present climate are raised by about 10% of both rainfed maize hybrids. It can be seen that when growing the late hybrid H708 rainfed maize, in both periods the yield losses are higher than those of the more resistant to drought, semi-early hybrid Kn-2L-611 by about 10% in the wet, up to 15% in the average and up to 20% in the high and very high irrigation demand years (Figs 3b and 3c). It is therefore advisable to grow drought-resistant semi-early maize hybrids in Sofia's field.

Evaluation of irrigation scheduling alternatives in the past (1952–1984) and present (1970–2004) climate

Figs 4a, 4b and 4c compare the simulated Available Soil Water (ASW, mm) under irrigation alternatives 1, 2 and 3 to the very high irrigation demand year 1963 ($P_I = 11\%$, Figure 3c) of the past climate (1952–1984). Irrigation up to 02/09 (solid line) with irrigation rates of 270, 240 and 240 mm can be seen to provide soil moisture during the most intensive development phase, with the greatest need of water, without any loss of yield. Suspension of the irrigation season to 20/08 (dotted line) leads to a reduction in the number of irrigations with one for all three alternatives 1, 2 and 3 and yield losses of 8.7, 9.0, 8.7% respectively. In this case, the last date of irrigation (20/08) is close to the one established (11/08) by Zahariev et al. (1986), but irrigation rates are lower than those published (300 mm) in 1986.

In comparison to the past climate, the very high irrigation demand year 1988 ($P_I = 13\%$) of the present climate, irrigation season starts about 20 days earlier for all three alternatives and ends at about the same time. During the dry years of the past climate, irrigation begins around 01/08, while in present climate conditions the start date is around 10/07. Number of irrigations increases by one for alternative 1 and by two for alternatives 2 and 3. When the last irrigation is submitted until 20/08, the optimum moisture supply decreases at the end of the growing season, at harvest, and results in yield losses of 8.8, 5.7, 3.8% respectively for alternatives 1, 2 and 3. For precise irrigation, without loss of yield, irrigation should end later on 03/09 (solid line) with one/two more irrigations.

During the high irrigation demand years 1954 and 1992 ($P_I = 25\%$), respectively, from the past and present climate, aiming at maximum yields irrigation should be until 05/09 (solid line, Figure 5). The numbers of irrigations of the three alternatives are identical for the two periods considered, with water saving alternatives 2 and 3 having irrigation rates of 240 mm, unlike alternative 1, which requires 270 mm of irrigation water.

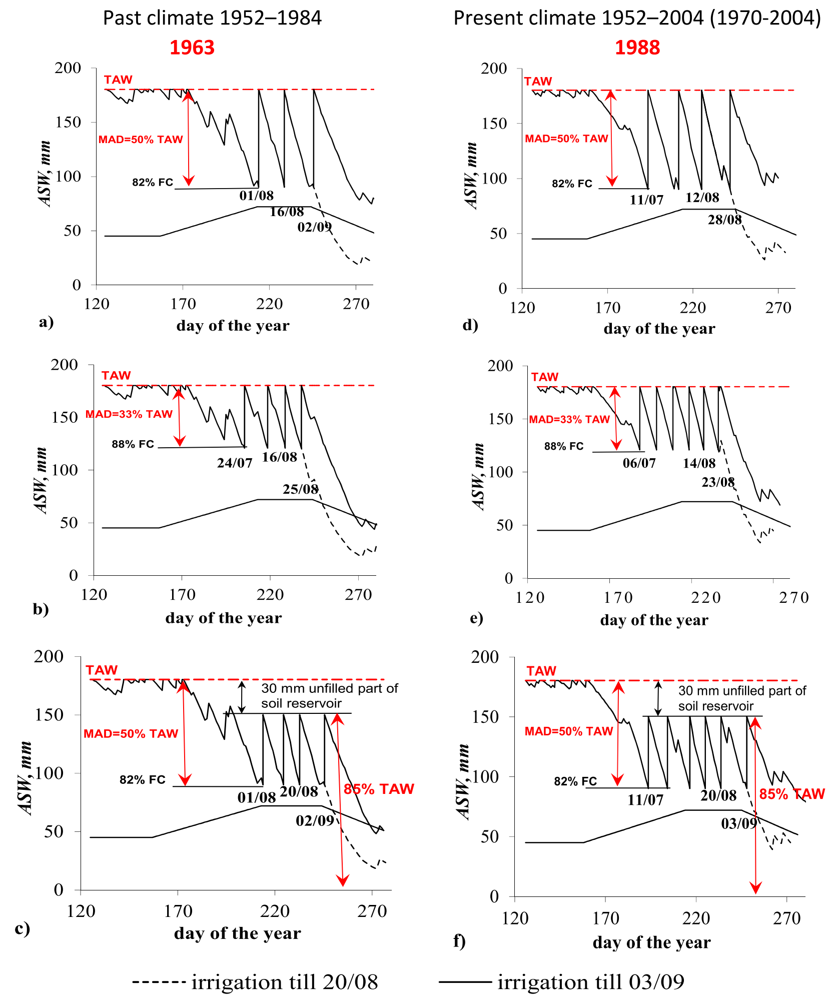

Figure 4 Simulation of the available soil water (ASW, mm) for the three irrigation scheduling alternatives in the very high irrigation demand 1963 and 1988 ($P_I = 11–13\%$) relative to past (1952–1984) and present (1970–2004) weather: a) and d) alternative 1; b) and e) alternative 2; c) and f) alternative 3, with identification of the date of the last irrigation. The horizontal dashed line above corresponds to TAW and the broken line below to the non-stress threshold

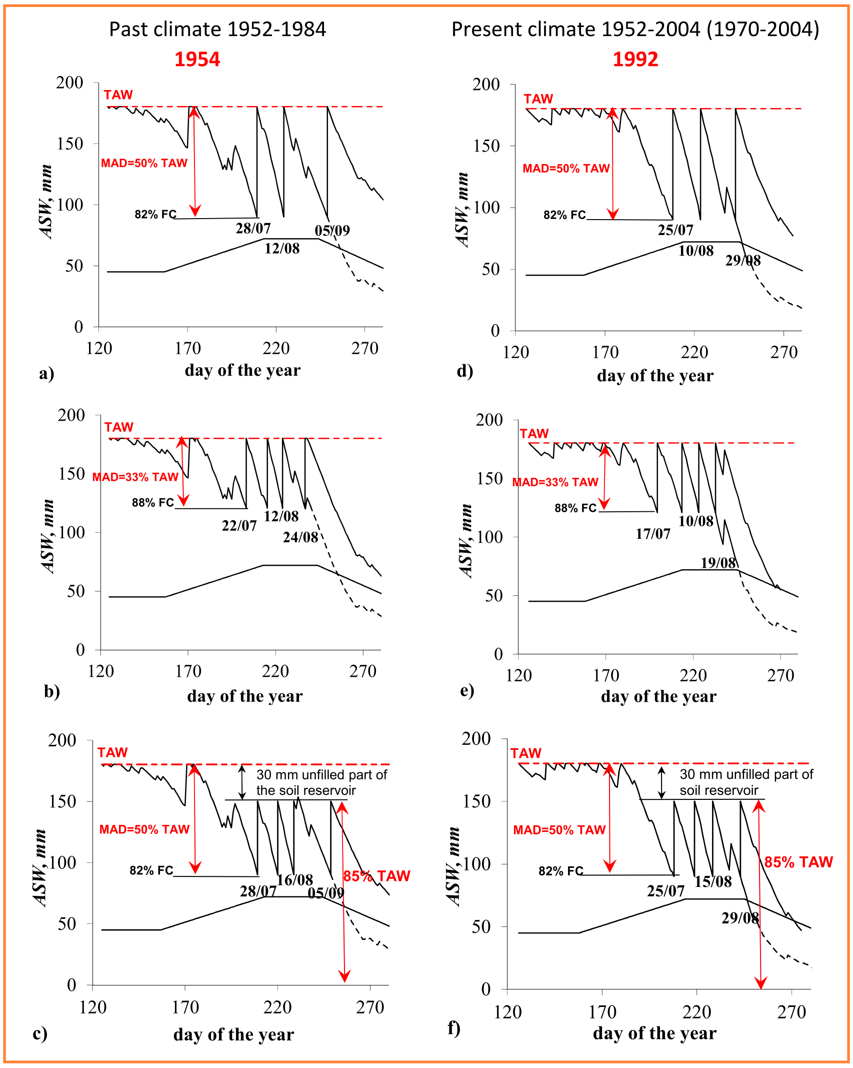

Figure 5 Available soil water (ASW, mm) for the three irrigation scheduling alternatives in the high irrigation demand 1954 and 1992 (P_I = 25%) relative to past (1952–1984) and present 1952–2004/ 1970–2004 weather conditions: a) and d) alternative 1; b) and e) alternative 2; and c) and f) alternative 3, with identification of the date of the first and last irrigation; The horizontal dashed line above corresponds to TAW and the broken line below to the non-stress threshold

Unlike the high irrigation demand year 1954 for the past climate, in 1992 from the present climate, irrigation began one week earlier. If one irrigation is cancelled, irrigation will end by 20/08 with yield losses of up to 5% in 1954 and up to 13% in 1992 for all three irrigation alternatives. During the 1992 to the present climate, irrigation seasons starts and ends several days earlier (Figure 5, Table 3). Also, under the present climate, ASW at harvest is lowering i.e. the usability of water reserves is increasing (Figure 5, Table 3).

A comparison on Figure 6a shows that the Irrigation Demands, IDs, i.e. the simulated applications of annual amount of irrigation water, of alternatives 1, 2 and 3 are close to NIRs for the past (1952–1984) climate, when very high demand years (P_I <12%) were irrigated till 05/09 and the rest years (P_I <98%) with up to 25/08. Irrigation rates of alternative 3, which allows greater degree of soil water depletion (MAD = 0.50) and better accumulation of rainfall in the maize root zone compared to alternatives 1 and 2, are closest to the NIR, leading to a 60 mm saving of water in the high irrigation demand (P_I = 12–30%) and average (P_I = 50–70%) years (Figure 6a). Alternative 2 has the highest irrigation rates in comparison with the other two alternatives, and for the most part of the probability of exceedance curve (P_I = 10–90%), they are above the NIRs. Alternative 1 saves 30 to 60 mm in the years having high irrigation demand (P_I = 10–30%). During the very high irrigation demand and average years, the irrigation rates under the three

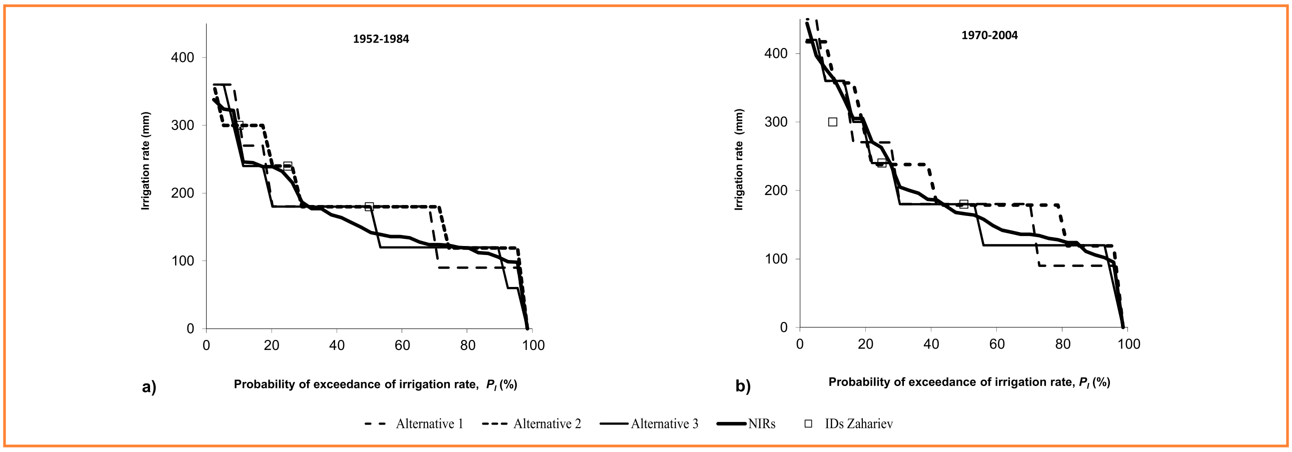

Figure 6 Irrigation Demands, IDs, mm, relative to irrigation scheduling alternative 1, 2 and 3 sorted according to the probability curve of Net Irrigation Requirements computed for each year of (a) 1952–1984 and (b) 1970–2004 using all required climate data on a daily basis

Table 3 Summary of water balance and relative yield decrease, RYD, results of irrigation scheduling alternatives 1, 2, 3 and rainfed alternative 4 for the very high and high irrigation demand years, 1952–1984* and 1952–2004/1970–2004. Last allowed irrigation date 03/09

Climate conditions	Very high irrigation demand								High irrigation demand							
	Past				Present				Past				Present			
	1952–1984				1952–2004				1952–1984				1952–2004			
Year	1963*				1988				1954*				1992			
P_I (%) 1952–2004	24%				9%				33%				22%			
P_I (%) 1952–1984*	11%				8%				26%				25%			
Precipit. May–Sept (mm)	267				197				236				311			
Precipit. Jul–Aug (mm)	90				18				87				64			
Net irrigation requirements (mm)	246				334				216				239			
Irrigation alternatives	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Annual amount of irrigation water (mm)	270	240		0	360		300	0	0	270		240	270	240		0
№ Irrigation events	3	4	4	0	4	6	6	0	3	4		0	3	4		0
Crop evapotranspiration (ETa) (mm)	577			353	593		586	309	548			368	553	545		324
Non-used precipitation (mm)	79				55	73	55	55	48	57	48		67			
ASW harvest (mm)	81	50		24	69	47	68	18	142	105		52	59	35		17
RYD (%) Ky = 1.21	0	0	0	46	0	0	0	58	0	0	0	40	0	0	0	50
RYD (%) Ky = 1.0				38				48				33				41
RYD (%) Ky = 1.6				60				77				53				6

alternatives are close to those previously published in the book of Zahariev et al. (1986) and used, whereas in the high irrigation demand seasons this refers only to traditional alternative 2, while alternatives 1 and 3 save irrigation rates of 60 mm (Figure 6a).

During the present climate (1970–2004), NIRs are significantly higher. Irrigation rates of alternative 3 are closest to NIRs, saving from 30 to 60 mm of water during the high irrigation demand and average years (Figure 6b). During the very high irrigation demand years, the irrigation rates for the three alternatives were by 60 to 100 higher than the published depths in the book of Zahariev et al. (1986), while in the high irrigation demand and average seasons they fluctuate around the NIRs and are close to those proposed in Zahariev et al. (1986). It is seen in the comparison between Figure 6a and 6b that NIRs and IDs became greater especially in very high and high demand years, as in the past IDs were lower than the ones published by Zahariev et al. (1986) but in the present they are higher. For the past climate (1952–1984) the NIRs and IDs are closer to those published in Zahariev et al. (1986) in the very high and high irrigation demand years, while in the present climate they are closer to the high and average irrigation demand years (Figs 6a and 6b).

Conclusions

The results are related to adapting irrigation scheduling to higher net irrigation requirements (NIRs, mm) of present climate conditions. The approach is applicable not only to other territory of Bulgaria, but everywhere in the world. The use of simulation models for irrigation management makes it possible to develop precise irrigation regimes that minimize water and yield losses.

From the simulated irrigation scheduling alternatives of maize grown on Vertisol soil at Sofia's field for the period 1952–2004 the following can be concluded:

1. Under the present climate conditions, NIRs have increased by 60–120 mm during the very high irrigation demand years (P_I <20%). In the remaining high and average irrigation demand years they raised with 40–100 mm and 10–40 mm respectively (Figure 2).
2. Losses of rainfed yields of late maize hybrids during the high irrigation demand years are in the range of 35–55% and about 70% during the very high irrigation demand years, whereas in the case of dry-resistant semi-early hybrids the impact of drought is mitigated and the yield losses do not exceed 55% during the very high irrigation demand years (P_I <8%). Due to the water stress, RYD in the present climate are raised by about 10% of both rainfed maize hybrids (Figure 3).
3. Adaptation of irrigation scheduling alternatives to the present climate during very high irrigation demand years (P_I ≤12%) consists of extending the irrigation season by 15–20 days and the need for additional irrigation at alternative 1 and two irrigations at alternatives 2 and 3 (Figure 4). In other years, adaptation to drought consists in precisely choosing the start and end dates for irrigation and extending or shifting the irrigation season.
4. During high irrigation demand years (P_I = 15–30%) irrigation without loss of yield should end by 05/09, as it begins and ends about a week earlier with the present climate. Alternatives 2 and 3 with IDs = 240 mm, compared

to 1 with IDs = 270 mm, save 30 mm of irrigation water over the two study periods (Figure 5).

5. In average irrigation demand years (P_I = 30–65%) irrigation for maximum yield results in the same irrigation rates of 180 mm in all three alternatives with the last allowed irrigation date of 15/08 for alternatives 1 and 2 and 22/08 for alternative 3 in both studied periods.
6. Simulations of the water saving and environmentally friendly, traditional alternative 2 for the conditions of the past climate lead to the same results as those published in thte book of Zahariev et al. (1986) for the average and high irrigation demand years. Alternative 2 also best describes the fluctuations in NIRs under the conditions of the "past" climate (Figure 6a). For the present climate conditions, this is valid for alternatives 2 and 3 for the high and average irrigation demand years, while in very high irrigation demand years all the three alternatives shows higher IDs (Figure 6b).

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