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Irrigation scheduling under climate uncertainties in North-West Bulgaria

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Abstract

The objective of the present study is to develop alternatives of precise irrigation scheduling for maize crop grown on a Degraded Chernozem soil in Gorni Dabnik experimental field and to define the impact of climate variability and change on irrigation management and yield relative to late and semi-early maize hybrids there over the period 1951-2004. The validated simulation model of water balance, irrigation scheduling and yield impacts of water stress WINISAREG is applied. The studied irrigation options are: (**1**) refilling soil reservoir to field capacity FC by adopting a management allowed depletion fraction **MAD**=0.47, i.e. up to **79%** of **FC**, and 90 mm application depths; (**2**) refilling soil reservoir to FC by adopting a depletion threshold **MAD**=0.31, i.e. pre-irrigation soil moisture 86% **FC**, and 60mm application depth; (**3**) aims at better storage and use of precipitation and irrigation water and consists of partial refilling the soil reservoir to 84% TAW by adopting **MAD**=0.47 and 60mm application depth. It has been found that: (**1**) Net irrigation requirements NIR vary from 0-10mm in extremely wet to 80-170 mm in the average, reaching 260 mm in the very dry 1963 of the past 1951-1984 period; (**2**) Schedule 2 leads to higher irrigation demands (**ID**) when compared with schedules 1 and 3, under which seasonal precipitation and soil water storage are more efficiently used and irrigation depths (**ID**) are 30 to 90 mm lower; (**3**) Relative to present weather condition, drought mitigation measures consists of application of environmentally oriented water saving schedules 1 and 3 with precise irrigation timing; (**4**) Considering the semi-early maize hybrids, as Pioneer 37-37 and Kneja-2L-611, yield impacts of water stress is mitigated. Yield losses relative to rainfed maize are 15-30% in the average year, while in the very dry year they do not surpass 60% of the potential yield.

Key words: Climate Variability and Change, Irrigation scheduling, WinISAREG model, Water Balance, North-West Bulgaria

North-West Bulgaria is affected by climate variability and increasing dryness (Alexandrov, 2011 Gregorič, 2012; Popova (ed.), 2012; Popova et al., 2013; Slavov et al., 2004). Detected climate change in “May-September” season creates uncertainties for maize irrigation scheduling and harvested yield there (Popova et al., 2014; 2015). To cope with them, simulations have been performed for past (1951-1984) and present (1951-2004) weather conditions using the validated water balance and irrigation scheduling simulation WinISAREG model for two maize hybrids of different sensitivity to water stress, both grown on a soil of large Total Available Water (**TAW**) (Pereira, 2003; Popova, Eneva, Pereira, 2006; Popova & Pereira, 2011). The model has been applied following an adaptation of soil and crop input parameters to local conditions at Gorni Dabnik experimental field near by Pleven.

Materials and Methods

The climate in Pleven is moderately continental with higher precipitation in spring and much lower in July and August when the average monthly sum is 55 and 30 mm respectively. Relative to the present observation period 1970-2004, it is found that precipitation totals relative to high irrigation demand "June-August" period may decrease by -1.8 mm yr^{-1} (fig. 1a). Contrarily, seasonal reference evapotranspiration computed by the **ETo-PM** equation (Allen et al.,1998) experiences a positive trend of annual increase by 2.3 mm yr^{-1} (fig. 1b).

The soil at Gorni Dabnik is a Degraded Chernozem (Stoyanov, 2008) that is wide - spread in the region (K. Boneva in Popova (Ed.), 2012). It consists mainly of silt (49 to 43%) and clay (37 to 43% for A- and B-horizon respectively) and has a large water holding capacity (**TAW**=168 mm m^{-1}) to accommodate for spring and summer precipitation.

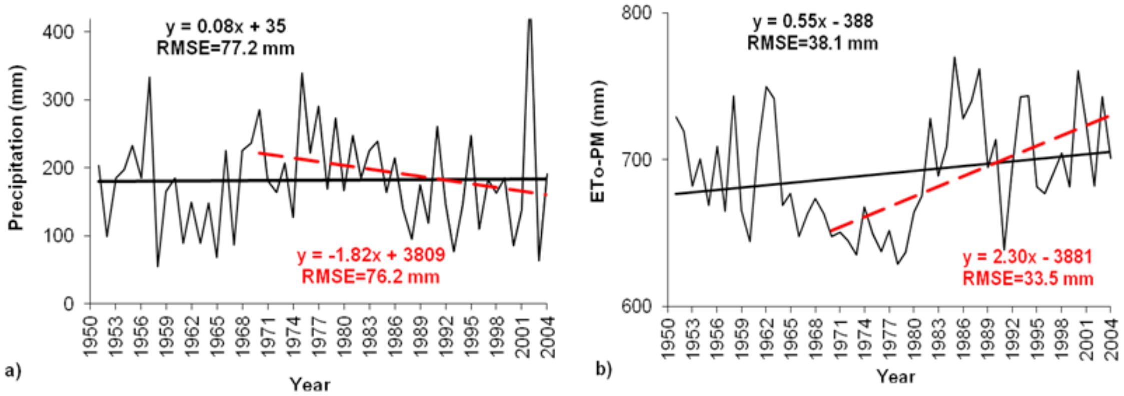


Fig.1 Variation of: (a) Precipitation sum for "June-August" period (mm) and (b) Seasonal ETo-PM "May-Sept" (mm), (—); trends relative to 1951-2004 (▬▬) and 1970-2004 (– –), Pleven

Parameters of main crop development stages and corresponding limiting dates, as well as crop coefficients (**Kc**) and depletion fraction for no stress (p), are presented in Table 1. The parameters are derived on the basis of our previous studies and field experiments with different irrigation treatments (Popova & Pereira, 2011; Popova, 2008; Popova (Ed.), 2012; Varlev, 2008) following an adaptation to soil and climate conditions at Gorni Dabnik experimental field. Maximum root depth is accepted to be 1.30 m.

Actual crop evapotranspiration **ETa** is computed from potential **ETmax** depending on readily available soil water. The evapotranspiration **ETmax** is computed using the crop coefficient **Kc** approach (**ETmax= Kc ETo**) (Allen et al.,1998).

Yield impacts of water stress are defined by the one-phase Stewart model (1-Ya/Ymax)= **Ky** (1-ETa/ETmax) (Stewart et al.,1977). Yield response factor **Ky** relative to rainfed maize has been previously derived using data from long-term field experiments with semi-early (**Ky**=1.2) and late (**Ky**=1.6) varieties (Rafailov and Jivkov in Varlev, 2008; Popova (Ed.), 2012) while a factor **Ky**=1.32 has been found when data from irrigation treatments of a mild stress have been used (Popova & Pereira, 2011).

The study compares several irrigation scheduling alternatives, which are built in agreement with past studies to develop environmentally sound irrigation practices that avoid soil cracking, high non-uniformity of water distribution, water and yield losses . **Alternative (1)** consists of refilling the soil reservoir by adopting a management-allowed depletion fraction (**MAD**) of 0.47 and 90 mm application depth both tuned to results of measurements under continuous furrow irrigation (Popova & Kuncheva, 1996; Popova et al.,1998) (fig. 2a).

Alternative (2) refills the soil reservoir by adopting **MAD**=0.31 and 60 mm application depth relative to surge furrow irrigation of improved distribution uniformity and reduced application depth or sprinkler irrigation (Popova et al.,1994; Varlev et al.,1998) (Fig. 2b) while Alternative (3) aims at better storage of seasonal precipitation by partially refilling soil reservoir adopting **MAD**=0.47 with 60 mm application depth (Popova, 2008; Popova & Pereira, 2008) (Fig. 2c). About 30 mm of soil reservoir remain unfilled to better accommodate for any precipitation fallen during the irrigation season; **Alternative (4)** refers to the option of crop without irrigation.

Table 1. Dates limiting crop development stages and modeling parameters: crop coefficients **Kc** and depletion fraction for no stress **p** , Leached Chernozem, Gorni Dabnik experimental field.

Crop development stages	Dates	Kc	p
Initial	30/04 to 19/05	0.3	0.45-0.75
Mid season	10/07 to 26/07	1.26	0.60
Full ripening	30/09 (harvest)	0.23	0.78

The maximum depth of the root zone is 1.30 m.

According to the regional irrigation practice and previous studies (Zahariev et al.,1986), the last allowed irrigation date is 31/07 for the high and the average irrigation demand years having probability of exceedance **P_I=25%** and **P_I=50%** respectively, while irrigation is extended up to 10/08 for the very high irrigation demand year having **P_I=10%**. These conditions are considered for all irrigation scheduling studies in addition to a free definition of irrigation timing aiming at water saving while avoiding yield losses.

Results and Discussions

To study impact of climate uncertainties in the region (fig. 1), simulations have been performed for three periods: the whole 1951-2004 period (fig. 3a) and the periods of present (1970-2004) (fig. 3b) and past (1951-1984) (fig. 3c) weather conditions. The irrigation scheduling WinISAREG model (Pereira et al.,2003) is applied for a semi-early *Pioneer P37-37* and a late *H708* maize hybrids with yield response factor **Ky**=1.2 with **Ky**=1.6 respectively, as evaluated by Popova and Ivanova (Popova (Ed.), 2012). Simulations are performed using the calibrated soil and crop modeling parameters and climate data consisting of average monthly minimum and maximum air temperature (**Tmax** and **Tmin**) and precipitation. In that case of limited climate dataset, the missing data have been computed by the procedures recommended by *FAO56* (Allen et al.,1998) after appropriate validation to the local climate (Popova, Kercheva, Pereira, 2006; Ivanova & Popova, 2011).

Considering the present climate (fig. 3b), it is observed that 2000, 1993, 1998 and 2003 are the very high irrigation demand years having probability of occurrence of a Net Irrigation Requirements, **NIR**, mm, **P_I**≤11% , while the moderate and the average irrigation demand years are 1974 (**P_I**=30%) and 1982 (**P_I**=48%) respectively. Comparing fig. 3a and fig. 3b, it is found that the years referred above have practically identical probability of a **NIR** occurrence **P_I** for the periods 1951-2004 and 1970-2004. The same holds true for the moderately wet 1984 (**P_I**=76%) and wet 1975 (**P_I**=96%).

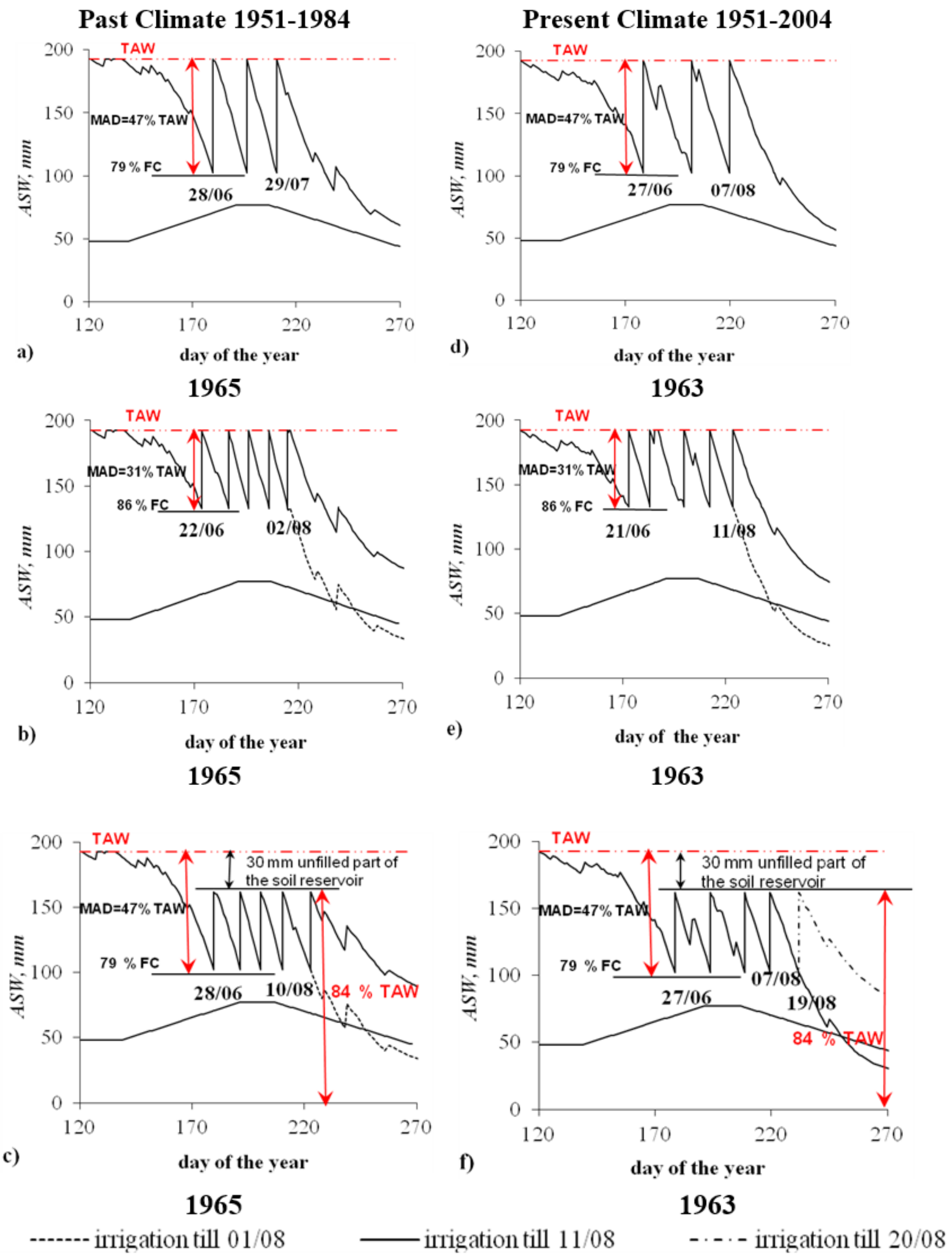


Fig. 2. Comparison of simulated available soil water (**ASW**^{1*}**, mm**) for the three irrigation scheduling alternatives in **the very high irrigation demand 1965** and **1963** (**P**$_I$=8%) relative to past (**1951-1984**) and present (**1951-2004**) weather: a) and d) alternative 1; b) and e) 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** ^{1**}, mm and the broken line, below, to the non-stress **OYT**^{1***} threshold

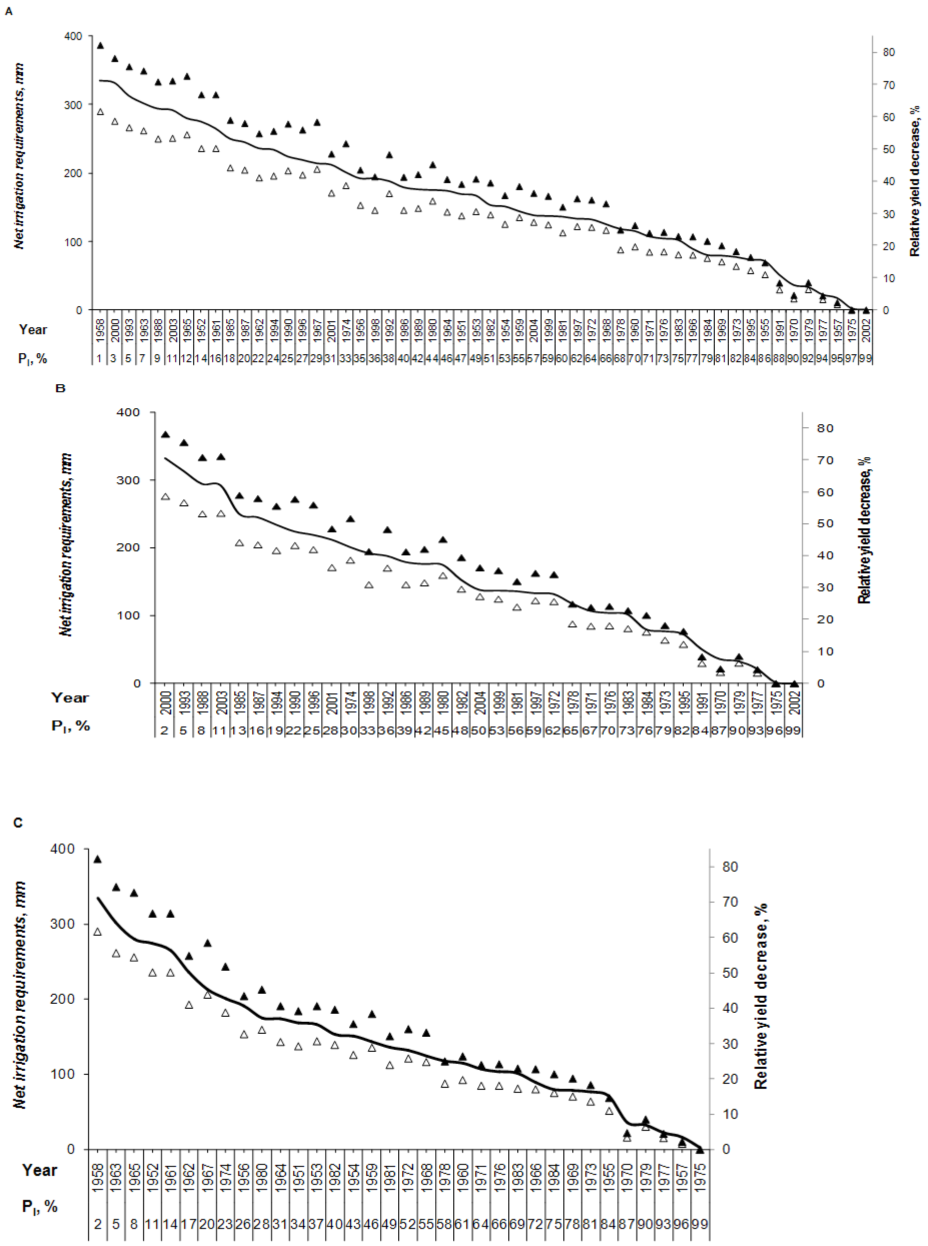


Fig. 3. Probability curves of occurrence of a Net Irrigation Requirements, NIR, mm, (─) and Relative Yield Decrease of rainfed maize, **RYD**,%, comparing the semi-early P37-37 (Δ), Ky=1.2, and late H708 (▲), Ky=1.6, hybrids relative to three periods: a) **1951-2004**; b) **1970-2004**; c) **1951-1984**; Simulations when average monthly temperature **Tmax, Tmin** and Precipitation data are used

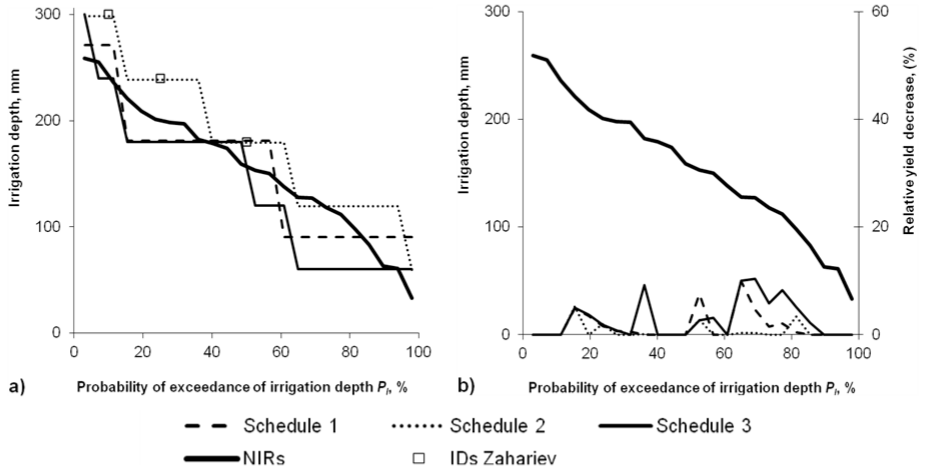


Fig. 4. Irrigation Demands, **IDs**, mm, (a) and relative yield decrease of irrigated maize, **RYD**,%, computed with Ky=1.32 (Popova & Pereira, 2011) (b) relative to irrigation scheduling alternatives 1, 2 and 3 simulated using all required climate data on a daily basis for each year of a 24-year period and sorted in relation to the probability curve of **NIR**.

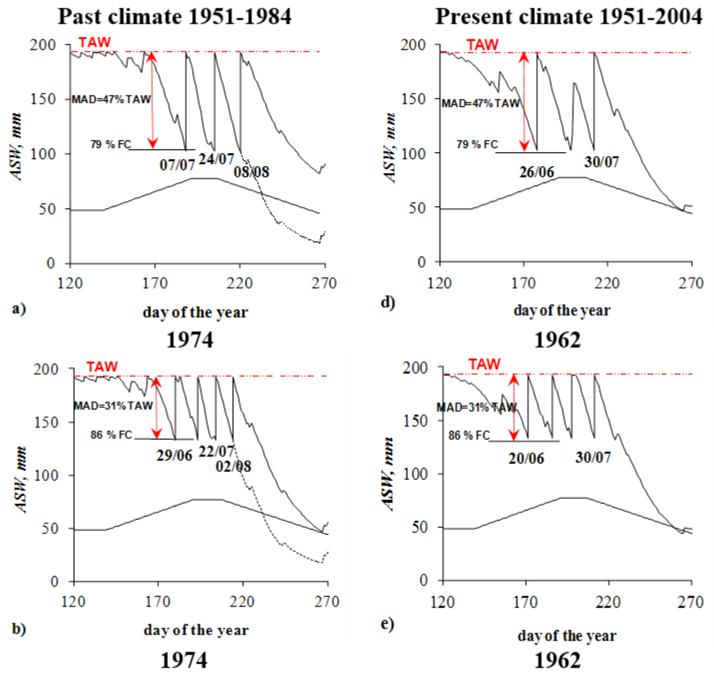


Fig. 5. Comparison of simulated available soil water (**ASW, mm**) for the three irrigation scheduling alternatives in **the high irrigation demand 1974** and **1962** (**P_I=22** and **23%**) relative to past (**1951-1984**) and present (**1951-2004**) weather conditions: a) and d) alternative 1; b) 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.

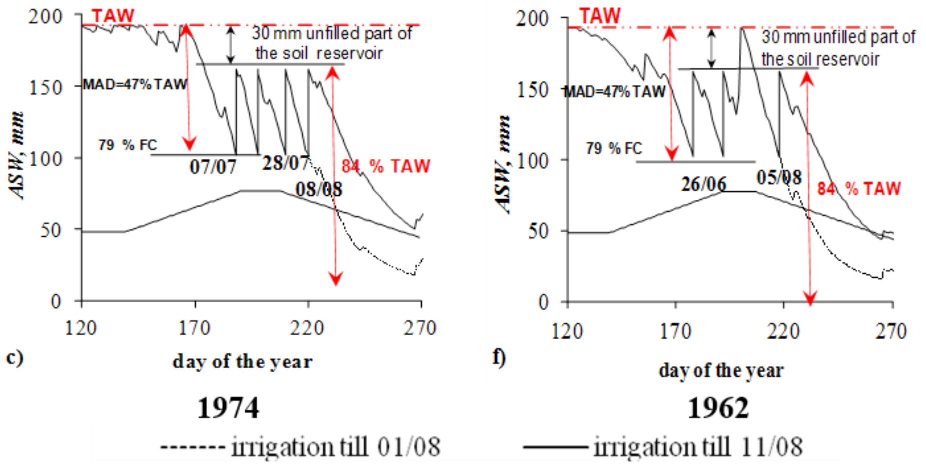


Fig. 5. Comparison of simulated available soil water (**ASW, mm**) for the three irrigation scheduling alternatives in **the high irrigation demand 1974** and **1962** (**P_I=22** and **23%**) relative to past (**1951-1984**) and present (**1951-2004**) weather conditions: a) and d) alternative 1; b) 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.

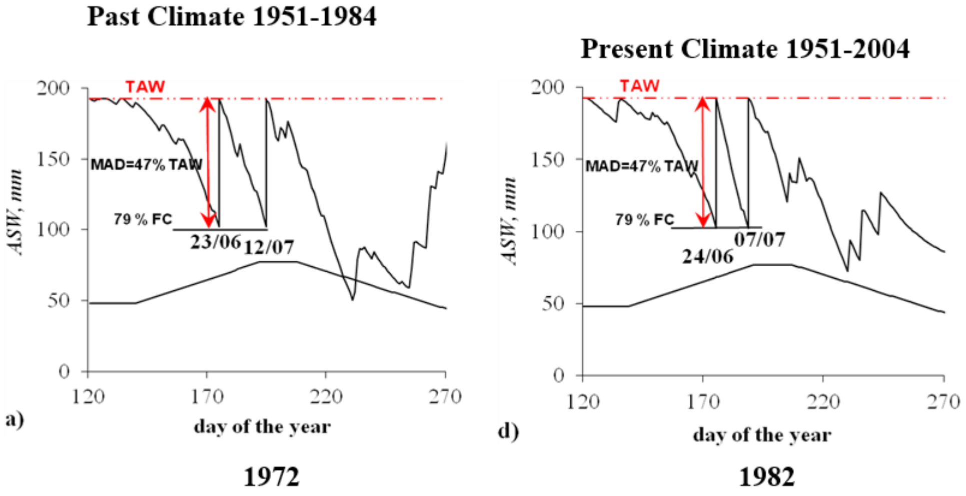


Fig. 6. Comparison of simulated available soil water (**ASW, mm**) for the three irrigation scheduling alternatives in **the average irrigation demand 1972** and **1982** relative to past (**1951-1984**) and present (**1951-2004**) weather conditions: a) and d) alternative 1; b) and e) alternative 2; and c) and f) alternative 3, with identification of the date of the first and last irrigation.

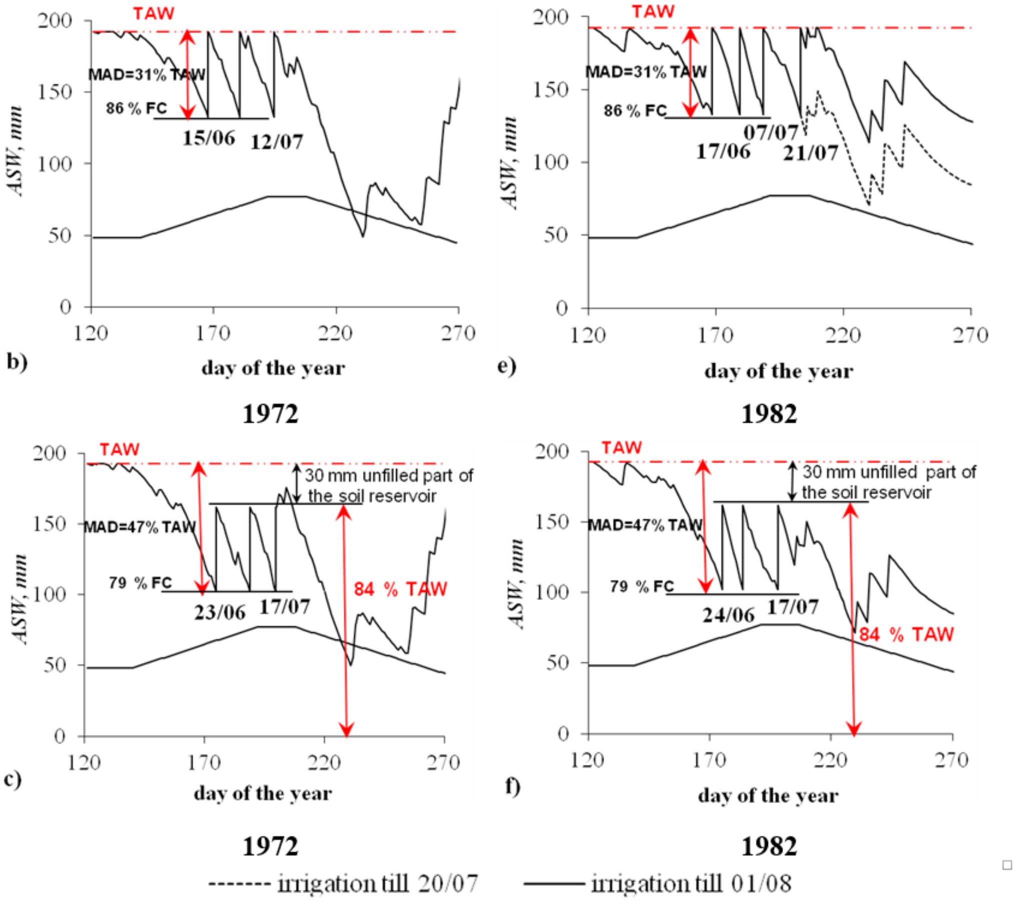


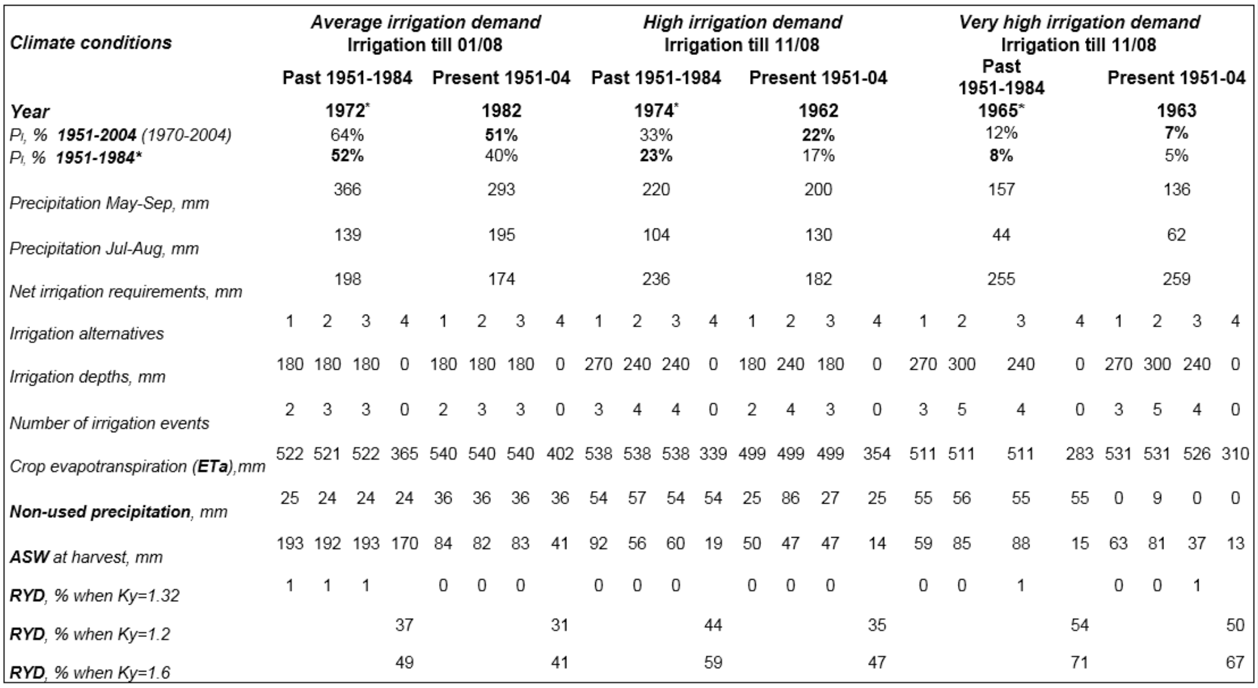
Fig. 6. Comparison of simulated available soil water (**ASW, mm**) for the three irrigation scheduling alternatives in **the average irrigation demand 1972** and **1982** relative to past (**1951-1984**) and present (**1951-2004**) weather conditions: a) and d) alternative 1; b) and e) alternative 2; and c) and f) alternative 3, with identification of the date of the first and last irrigation.

Thus, it is concluded that the results relative to maize irrigation requirements **NIR**, mm, and yield losses due to water stress **RYD**, %, are practically identical for both periods 1951-2004 and 1970-2004 (Figs. 3a and 3b).

Simulations carried out with all required climate data on a daily basis (Allen et al., 1998) relative to **the very high irrigation demand 1965** (**P**$_I$=8%, fig.3c) show that scheduling alternatives 1, 2 and 3 lead to different irrigation demands (**ID**s) of 270, 300 and 240 mm (figs. 2a; 2b; 2c). The probability curves of **ID**s at Gorni Dabnik over the period 1961-1984 show that the respective irrigation thresholds and application depths produce demands that are also different among them (fig. 4a)

The IDs relative to Alternative 2 are the highest among the three alternatives and are often larger than net irrigation requirements (**NIR**). Alternatives 1 and 3 allowing a larger depletion lead to water saving of 30 to 90 mm when compared with alternative 2 over the whole range of climate variability and change in the period 1961-1984. These results are compared to irrigation scheduling presently advised in the region (Zahariev et al.,1986) and show that the latter covers crop irrigation demands and timing computed with alternative 2 (figs. 4a and 2b). The impacts on yields caused by the irrigation alternatives are also different among them being larger with schedule 3 (**RYD**=2.8% on the average with a maximum of **RYD**=10.4% in 1971) and negligible with schedule 2 (average **RYD**=0.6% with a maximum of **RYD**=5.2% in 1961) (fig.4b).

Table 2. Summary water balance and relative yield decrease, **RYD**, results of irrigation scheduling alternatives 1, 2, 3 and rainfed alternative 4 for the average, high and very high irrigation demand years, **1951-1984*** and **1951-2004**. Last allowed irrigation date **01/08** for the average demand and **11/08** for the high demand years.



Climate conditions	***Average irrigation demand*** **Irrigation till 01/08**								***High irrigation demand*** **Irrigation till 11/08**								***Very high irrigation demand*** **Irrigation till 11/08**							
	Past 1951-1984				**Present 1951-04**				**Past 1951-1984**				**Present 1951-04**				**Past 1951-1984**				**Present 1951-04**			
Year	**1972***				**1982**				**1974***				**1962**				**1965***				**1963**			
P$_I$, % ***1951-2004*** *(1970-2004)*	64%				**51%**				33%				**22%**				12%				**7%**			
P$_I$, % ***1951-1984****	**52%**				40%				**23%**				17%				**8%**				5%			
Precipitation May-Sep, mm	366				293				220				200				157				136			
Precipitation Jul-Aug, mm	139				195				104				130				44				62			
Net irrigation requirements, mm	198				174				236				182				255				259			
Irrigation alternatives	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Irrigation depths, mm	180	180	180	0	180	180	180	0	270	240	240	0	180	240	180	0	270	300	240	0	270	300	240	0
Number of irrigation events	2	3	3	0	2	3	3	0	3	4	4	0	2	4	3	0	3	5	4	0	3	5	4	0
*Crop evapotranspiration (**ETa**),mm*	522	521	522	365	540	540	540	402	538	538	538	339	499	499	499	354	511	511	511	283	531	531	526	310
***Non-used precipitation**, mm*	25	24	24	24	36	36	36	36	54	57	54	54	25	86	27	25	55	56	55	55	0	9	0	0
***ASW** at harvest, mm*	193	192	193	170	84	82	83	41	92	56	60	19	50	47	47	14	59	85	88	15	63	81	37	13
***RYD**, % when Ky=1.32*	1	1	1		0	0	0		0	0	0		0	0	0		0	0	1		0	0	1	
***RYD**, % when Ky=1.2*				37				31				44				35				54				50
***RYD**, % when Ky=1.6*				49				41				59				47				71				67

1*ASW = Available soil water in the root zone, mm
2** TAW = total available soil water, , mm m-1
3*** OYT = optimum yield threshold, OYT=p×TAW

Adaptation of irrigation scheduling alternatives 1, 2 and 3 to present weather in t**he very high irrigation demand 1963** (**P$_I$**=7%, fig.3a) consists only of precise irrigation timing and extending the irrigation season by a decade (fig. 2d, 2e, 2f). That is due to the fact that Precipitation and Available Soil Water (**ASW**) are very efficiently used then (table 2).

Regarding **the high irrigation demand 1974** of the past climate (**P$_I$**=23%, fig. 3c), the last allowed irrigation date is 11/08 with all the three alternatives when aiming at maximum yield (fig. 5a, 5b, 5c, table 2). So, Alternative 2 requires **IDs=240 mm** (4 irrigation events) – the first one scheduled at the end of June and the next three in July (fig. 5b) that mach to the currently adopted irrigation scheduling for the Degraded Chernozem in the region (Zahariev et al.,1986). However in **the high irrigation demand 1962** of the present weather (**P$_I$**=22%, fig. 3a), it is observed that schedules 1 and 3 allowing a larger depletion save each an irrigation in July due to the fact that a 60 mm rain is accumulated in the root zoon then (fig. 5d and 5f).

In the average irrigation demand 1972 of the past weather (**P$_I$**=52%, fig. 3c) all three irrigation scheduling alternatives produce equal **ID**s of 180mm and high level of available soil water at harvest **ASWend**=193mm (fig. 6a, 6b, 6c, table 2), **while in the average 1982** of the present weather (**P$_I$**=51-48%, fig. 3a 3b) an useless irrigation event could be scheduled if keeping up with the irrigation timing recommended by Zahariev et al. (1986) (fig. 6e). Contrarily to 1972, in 1982 available soil water at the end of season **ASWend** is depleted to **optimum yield threshold (OYT)** (fig. 6d, 6e, 6f; table 2).

Conclusion

To assess how past (1951-1984) and present (1951-2004) weather conditions could affect irrigated agriculture at Gorni Dabnik, simulations of different environmentally sound irrigation scheduling alternatives were performed. For the past weather, **NIRs** range from 0 in extremely wet seasons to 110-170 mm in the average irrigation demand years (40 $\leq$**P$_I$**$\leq$75%) reaching 260 mm in the very high demand 1963 (**P$_I$**=8%). For the present weather, **NIRs** have increased by 10-30 mm in the high and average demand years. Simulations for every year during a 24-year period using all required data on a daily basis have shown that Alternative 3, allowing a larger soil water depletion (**MAD**=0.47) and partially refilling the soil reservoir, leads to the best storage of precipitation and requires 60 mm less irrigation water than the one having **MAD**=0.31. Water saving effect of Alternative 1 (**MAD**=0.47) that refills soil reservoir to **FC** varies between 30 and 90 mm. Due to the fact that Precipitation and **ASW** are much more efficiently used when adopting alternatives 1 and 3, adaptation of irrigation to the changing climate at Gorni Dabnik consists of practical application of these alternatives when irrigation timing is adjusted, including extension of the irrigation season after the conventional date in the very high irrigation demand years. Analyses show that alternative 2 leads to less impact on yield. Relative to the rainfed crop, the results indicate that coping with changing climate and water saving restrictions requires adopting less sensitive maize hybrids.

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