IRRIGATION SCHEDULING FOR MAIZE UNDER CHAINGING NORTHERN BLACK SEA CLIMATE

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Abstract: *The region of Varna proved to be a driest in terms of precipitation in this country. Trend test applied to climate datasets reviled a significant increase for seasonal* ***reference evapotranspiration ETo*** *during 1970-2004. Detected climate variability&droughts create uncertainties for maize irrigation scheduling and harvested yield. To cope with them, simulations have been performed for past (1951-1984) and present (1951-2004) weather conditions using the validated water balance WinISAREG simulation model for two maize hybrids of different sensitivity to water stress grown on a Haplic Chernozem soil of medium water holding capacity. The study compares three irrigation scheduling alternatives built in agreement with past studies to develop environmentally sound/water saving irrigation technologies that consist of refilling the soil reservoir by adopting a* ***management-allowed depletion fraction*** *(****MAD****): (1) MAD=0.50; (2) MAD=0.33; (3) MAD=0.50 but partially refilling the soil reservoir. Simulations relative to the very high irrigation demand year of the current weather show that when aiming at maximum yield all three scheduling alternatives require the same* ***irrigation depths ID****=360mm that is 60 mm higher than conventional advised in the region. In the average demand years of past and current weather, Alternative 1 requires the same* ***ID****=270mm while a smaller* ***ID****=240mm is simulated with both alternatives 2 and 3 due to the fact that* ***available soil water ASW*** *is presently depleted to the* ***optimum yield threshold OYT*** *at harvest.*

Keywords: CLIMATE VARIABILITY/CHANGE, NORTHERN BLACK SEA COAST, IRRIGATION SCHEDULING, MAIZE, WINISAREG MODEL, WATER SAVING, YIELD

1. Introduction

Varna agricultural region, situated in the Northern Black Sea climate zone, proved to be exceptionally dry in term of annual and seasonal precipitation (Alexandrov (Ed) 2011; Slavov et al, 2004; Popova (Ed) 2012; Popova et al.2014; 2015). Trend test applied to local climate data shows that relative to reference evapotranspiration ***ETo-PM*** for maize crop season, a significant trend of increase by +2.6 mm yr^{-1} is observed for the period 1970-2004 (Fig.1b).

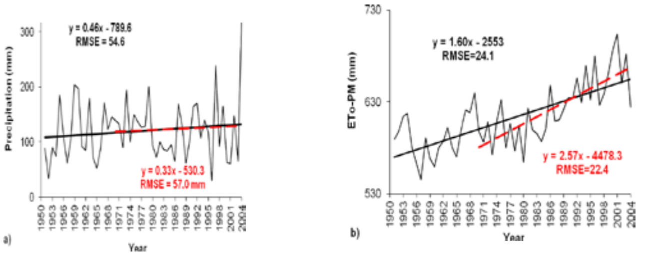


Fig. 1 *Variation of: (a) Precipitation sum for "June-August" period (mm) and (b) Seasonal ETo-PM "May-Sept" (mm), (—), Varna; trends relative to 1951-2004 (▬▬) and 1970-2004 (— —).*

Detected climate variability and change (Fig.1) creates uncertainties for maize irrigation scheduling and harvested yield there. To cope with them, simulations have been performed for past (1951-1984) and present (1951-2004) weather conditions using the validated irrigation scheduling simulation WinISAREG model (Pereira et al., 2003) for two maize hybrids that were subject of former studies, the semi-early Pioneer P37-37 and the late H708, considering a wide spread Haplic Chernozem soil in the region (Popova et al., 2006b; Stoyanov, 2008; Boneva in Popova (Ed), 2012 Popova et al., 2014).

2. Materials and Methods

The WinISAREG model, as described by Pereira et al. (2003), uses the soil water balance approach and the updated methodology proposed by Allen et al. (1998) to compute crop ***ET*** and irrigation requirements. Data required consist of: (1) weather data on precipitation and reference evapotranspiration ***ETo***; (2) soil water data, the ***total available soil water*** (***TAW***, mm m^{-1}), i.e. the difference between soil water storage at ***field capacity FC*** and ***wilting point WP*** for a soil depth of 1.0 m, and (3) crop data relative to the main crop development stages and corresponding dates, crop coefficients ***Kc***, root depths and the soil water depletion fractions for no stress ***p***. The model allows various simulation options including to simulate an irrigation schedule using selected irrigation thresholds, executing the water balance without irrigation, computing ***net irrigation requirements NIR.Relative yield decrease*** due to water stress ***RYD*** is estimated by Stewart one-phase model (1977) when ***yield response factor Ky*** is known.

Data on soil genesis&texture, ***FC, WP***, bulk density (Table 1) are used to define the *water holding capacity of the soil* ***TAW=157 mm m^{-1}*** in the study (Boneva in Popova (ed.) 2012).

Table 1. *Main soil hydraulic properties relative to a Haplic Chernozem soil, North East Bulgaria* (Stoyanov, 2008).

Horizon	Depth, *cm*	Bulk density at ***FC****, g cm^{-3}*	*Soil moisture, fractions in weight*	
			Field capacity	*Wilting point*
A1	0-10	1.14	0.25	0.12
	10-20	1.19	0.26	0.12
	20-30	1.33	0.24	0.12
A2	30-50	1.35	0.24	0.13
	50-70	1.35	0.24	0.12
A3	70-115	1.44	0.23	0.12

The previously validated crop parameters, as described by Popova et al. (2006b), Popova (2008), Popova and Ivanova in Popova (ed.) (2012), have been presently used after respective adaptation to local climate and soil conditions (Table 2).

Table 2. *Dates of maize development stages and respective crop coefficients (****Kc****) and soil water depletion fractions for no stress (****p****) for maize grown on a Haplic Chernozem soil in the Varna region.*

Growth phases	Initial period	Mid-season	End-season
Dates	26/04 to 19/05	15/07 to 09/08	30/09 (harvest)
Kc	0.28	1.28	0.35
p	0.45-0.75	0.65	0.80

The report compares several irrigation scheduling alternatives built in agreement with past studies to develop environmentally sound and water saving irrigation technologies that avoid soil cracking by maintaining soil moisture above 75% ***FC***, high non-uniformity of water distribution, water and yield losses (Popova et al., 1994; 1998; Popova&Kuncheva, 1996; Varlev et al., 1998): Alternative (1) consists of refilling the soil reservoir by adopting a management-allowed depletion fraction ***MAD***=0.50, i.e. to 76% ***FC***, and 90 mm application depth tuned to continuous furrow irrigation (Fig.2a); Alternative (2) consists of refilling the soil reservoir by adopting a smaller ***MAD***=0.33, i.e. to 84% ***FC***, and 60 mm application depth relative to sprinkler or surge furrow irrigation of improved distribution uniformity and reduced application depth (Fig.2b); Alternative (3) aims at better storage of seasonal precipitation by adopting ***MAD***=0.50 and partially refilling soil reservoir to 83%***FC*** with 60 mm application depth (Fig.2c).

According to the regional irrigation practice (Zahariev et al, 1986), the last allowed irrigation date is 21/08 for an average and a high irrigation demand year having ***probability of exceedance of irrigation depth*** P_I=50% and P_I=25% and 31/08 for the year of very high irrigation demand (P_I=10%). These conditions are considered for all studied irrigation scheduling alternatives in addition to a free definition of irrigation timing aiming at water saving while avoiding yield losses. Alternative (4) refers to the option crop without irrigation. Climate data observed on a daily basis, namely minimum and maximum air temperature T_{max} and T_{min}, relative air humidity, wind speed and solar radiation computed by using the temperature difference method with coefficient K_{Rs}=0.19 adjusted to "coastal" location (Allen et al. 1998) are used when simulating irrigation scheduling alternatives referred above. As a second option, monthly precipitation and ***ETo*** series (1951 to 2004), with ***ETo*** computed as described in Popova et al. (2006a), have been used to build probability curves of occurrence of a ***NIR*** and respective ***RYD*** relative to rainfed maize semi-early and late hybrids (Fig.3).

3. Results and Discussions

The results of simulations of ***ASW*** for the three irrigation scheduling alternatives are presented in Figs.2a 2b 2c for **1953** that is a very high demand year (P_I=8%) of the past climate 1951-1984 (Fig.3b). If aiming at maximum yield, irrigation scheduling alternative 1 requires 4 irrigation events of 90 mm and alternatives 2 and 3 require 6 events of 60 mm, thus the same demands ***ID***=360 mm for all three alternatives (full line refers to the last irrigation applied before 31/08). However if a negligible yield decrease ***RYD***<1% is accepted (dashed line in Figs. 2b 2c), alternatives 2 and 3 fully cover conventional crop irrigation timing and demands ***ID***=300 mm (Zahariev et al.1986) and ***NIR***=315 mm.

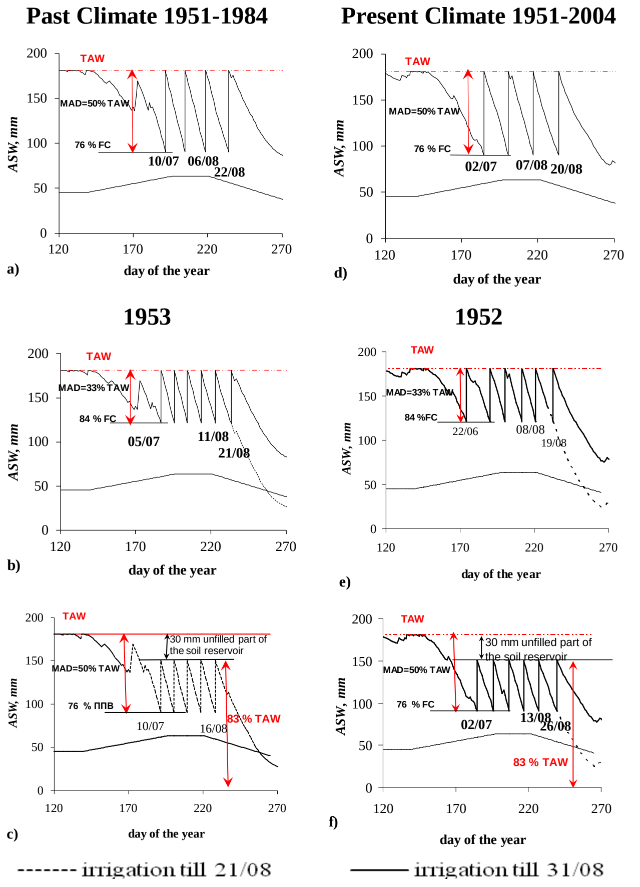


Fig.2. *Available soil water (****ASW,*** *mm) for the three irrigation scheduling alternatives in* ***the very high irrigation demand 1953 and 1952*** *(*P_I*=8 %) relative to past (1951-1984) and present (1951-2004) weather: a) and d) alternative 1; b) and e) alternative 2; and c) and f) alternative 3, with identification of the date of the first and last irrigation; The horizontal dashed line, above, corresponds to* ***TAW*** *and the broken line, below, to the non-stress* ***OYT*** *threshold.*

Simulations for **1952** representing the very high irrigation demand year in the last 54 years (P_I=7%, Fig. 3a) show that a larger yield decrease occurs when keeping up with presently advised irrigation demands of 300 mm (the dashed line in Figs.2e 2f). Adaptation to changing climate consists of an earlier timing for first irrigation event that requires a seasonal irrigation depth of 360 mm.

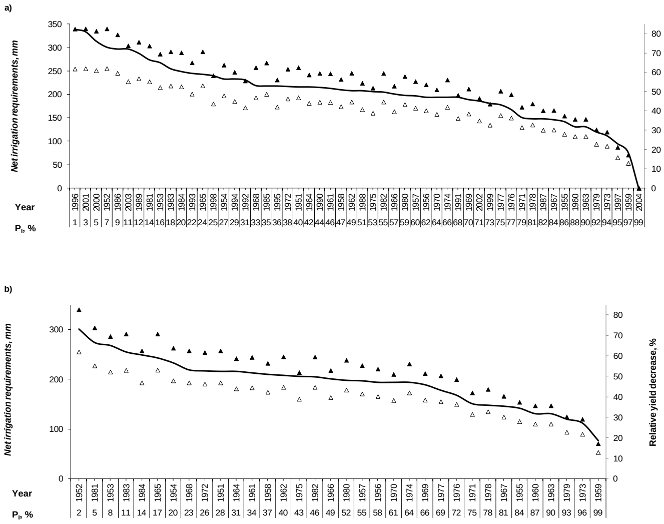


Fig. 3 *Probability curves of occurrence of a Net Irrigation Requirements,* ***NIR****, mm, (—) and Relative Yield Decrease of rainfed maize,* ***RYD****,%, comparing the semi-early P37-37 (Δ), Ky=1.2, and late H708 (▲), Ky=1.6, hybrids relative to two periods: a) 1951-2004; b) 1951-1984; Simulations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

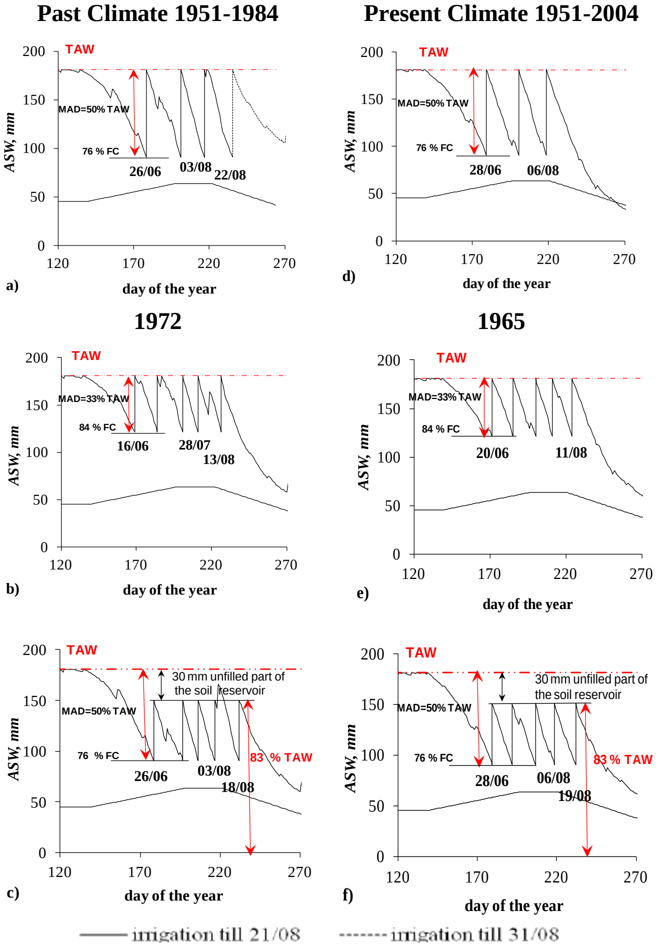


Fig.4. *Available soil water (****ASW,*** *mm) for the three irrigation scheduling alternatives in* ***the high irrigation demand 1972 and 1965*** *(*P_I*=25 %) relative to past (1951-1984) and present (1951-2004) weather: a) and d) alternative 1; b) and e) alternative 2; and*

c) and f) alternative 3, with identification of the date of the first and last irrigation;

Comparing *ASW* (Fig.4) and summary of results (Table 3) for all alternatives for the high irrigation demand year (P_I=25%) relative to past (**1972**) and present (**1965**) climate conditions show that alternative 1 results in a different date of last irrigation (22/08 *vs*. 6/08), number of required irrigation events (4 *vs*.3) and depths (360 *vs*.270 mm) and ***ASW*** at harvest (130 *vs*.31 mm). Contrarily, alternatives 2 and 3 adapt better to climate uncertainties requiring the same ***ID***=300 mm regardless unfavorable distribution of seasonal precipitation in 1965 (Figs.4b 4c 4e 4f; Table 3). Referring to Alternative 2, it fully covers again currently adopted irrigation timing and demands, as described by Zahariev et al. (1986).

Results of *ASW* simulations for the average demand year (P_I=50%) in the period 1951-1984 (**1980**) and in the last 54 years (**1975**) are shown in Fig.5. Relative to the high demand **1972** (Figs.4a 4b 4c) the number of irrigation events reduces from 4, 5 and 5 to 3, 4 and 4 for alternatives 1, 2 and 3 respectively. Thus irrigation scheduling alternative 1 requires the same irrigation depths of 270 mm (Figs.5a 5d) while alternatives 2 and 3 save water requiring 240mm (Figs.5b 5c 5e 5f; Table 3). Comparing alternatives 1 and 3 that have the same ***MAD***, the higher ***ASW*** at harvest and irrigation demand for alternative 1 result from the fact that application depths for this one are larger than for the other (90 mm *vs*. 60 mm). Abundant spring rainfalls in 1975 are not accommodated in the root zone while the available soil water ***ASW*** is depleted to optimum yield threshold ***OYT*** at harvest (Table 3).

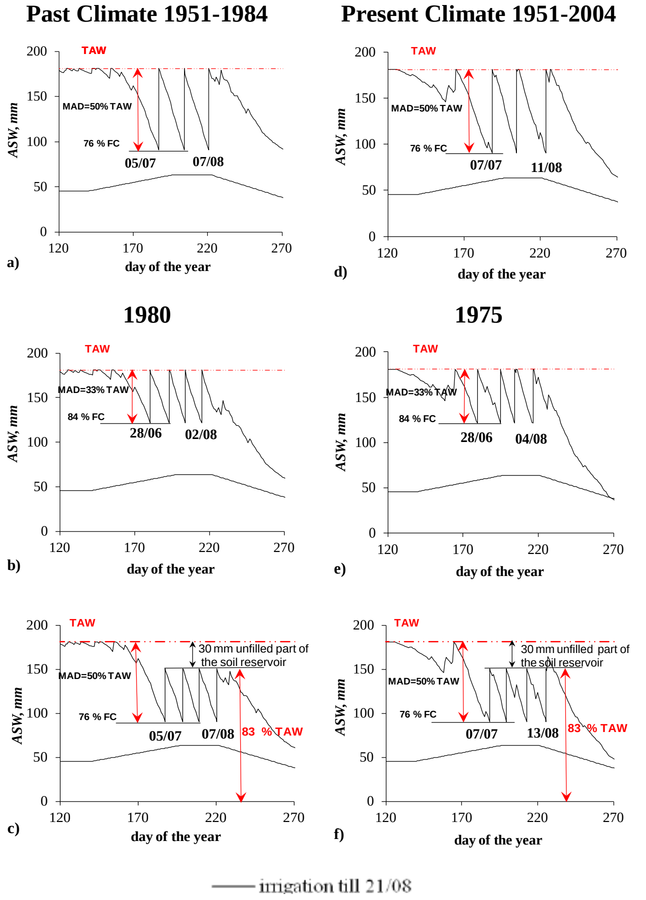


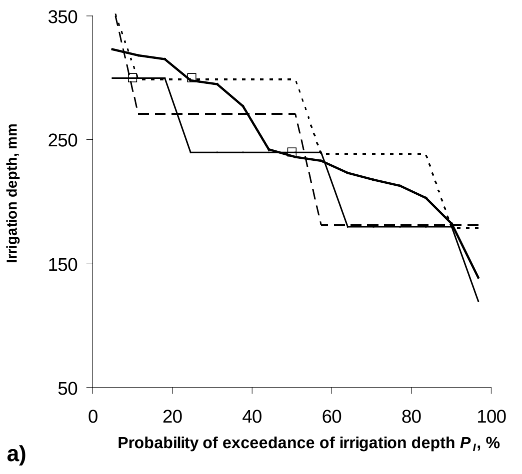
Fig.5. *Available soil water (**ASW,** mm) for the three irrigation scheduling alternatives in **the average 1980** and **1975** (P_I=52%) relative to past (1951-1984) and present (1951-2004) weather: a) and d) alternative 1; b) and e) alternative 2; and c) and f) alternative 3, with identification of the date of the first and last irrigation.*

Referring to each year of the past weather in 1951-1984, ***NIR*** ranges from 80 mm for the very wet 1959 (P_I=99%) to 150-210 mm in the moderate demand years ($40<P_I<75\%$) reaching 300 mm in the very dry 1952 (P_I=2%, Fig.3b*)*. Relative to rainfed maize, *H708 variaty*, same period, yield decrease ***RYD*** varies within the limits of 20% in 1959 to 40-60% in the average years reaching 83% in the extreme demand 1952 (Fig.3b). Semi-early maize hybrids, as *Pioneer (P37-37)* and *Kn-2L-611*, mitigate yield losses to 40<***RYD***<45% in the average and 62% in the very high irrigation demand years. Climate change in the last 54 years is characterized by a higher frequency and intensity of drought, larger number of extremely dry years with maximal ***RYD*** for maize without irrigation (4 *vs*. 1 in the past) and increased ***NIR*** in average and dry seasons of $P_I\leq75\%$ by 30-35 mm (Figs.3a 3b).

Table.3 *Summary water balance and relative yield decrease,**RYD**,relative to irrigation scheduling alternatives 1, 2, 3 and rainfed alternative 4 for the average and high irrigation demand years, 1951-1984* and 1951-2004. Last allowed irrigation date 21.08.*

Climate conditions	***Average irrigation demand***								***High irrigation demand***							
	Past **1951-1984**				**Present** **1951-2004**				**Past** **1951-1984**				**Present** **1951-2004**			
Year	**1980***				**1975**				**1972***				**1965**			
***P_I*, %, 1951-2004**	59%				**53%**				38%				**24%**			
P_I*, %, 1951-1984	**52%**				43%				**26%**				17%			
***Prec. May-Sep*,mm**	**166**				**209**				**158**				**135**			
***Prec. Jul-Aug*, mm**	**56**				**86**				**66**				**35**			
Net irrigation requirements, mm	**219**				**231**				**280**				**277**			
Irrigation alternatives	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Season Irrigation Depths* (*ID*), *mm	***270***	***240***		*0*	***270***	***240***		*0*	***360***	***300***		*0*	***270***	***300***		*0*
№ irrigation events	***3***	***4***	***4***	***0***	***3***	***4***	***4***	***0***	***4***	***5***	***5***	***0***	***3***	***5***	***5***	***0***
Crop evapotranspiration* (*ETa*), *mm	***484***			***293***	***539***			***339***	***534***			***287***	***502***			***255***
Non-used precipitation, mm	***34***				***158***		***144***		48	***33***			***60***			
ASW harvest, mm	**97**	***65***		**17**	**63**	**35**	**46**	***6***	***130***	***84***		**32**	**31**	***58***		***8***
***RYD*,%, *Ky*=1.32**	*0*	*0*	*0*		*0*	*0*	*0*		*0*	*0*	*0*		*0*	*0*	*0*	
***RYD*,%, *Ky*=1.2**				***47***				***47***				***56***				***59***
***RYD*,%, *Ky*=1.6**				***63***				***59***				***74***				***79***

Fig.6 illustrates the simulated results relative to 15 consecutive years when using full required climate data series observed on a daily basis.



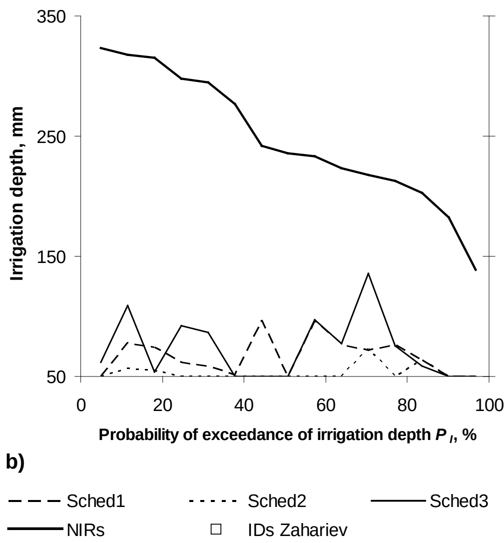


Fig.6. *Irrigation Demand,* ***ID****, mm, (a) and relative yield decrease,* ***RYD****, %, computed with* ***Ky****=1.32 (Popova and Pereira, 2011)(b) relative to irrigation alternatives 1,2 and 3 simulated with 21/08 as a last allowed irrigation date, sorted in relation to* irrigation depth *1951-1965 using all required climate data observed on a daily basis*

The respective irrigation thresholds and application depths produce demands that are mostly different among them (Fig.6a). Simulations for each year during the period have shown that Alternative 3 allowing a larger soil water depletion (***MAD***=0.50) and partially refilling the soil reservoir leads to better storage of precipitation requiring 60 mm less irrigation water than the one having ***MAD***=0.31. The water saving effect of Alternative 1 (***MAD***=0.50) varies between 30 in dryer (P_I<55%) and 60 mm in wetter (P_I>60) seasons. Simulation results are compared to irrigation scheduling presently advised in the region (Zahariev et al.1986) showing that the latter covers ***ID*** computed with alternative 2 in the high and very high demand years (Figs. 6a). The impacts on yields caused by the irrigation alternatives are also different among them (Fig.6b) being larger with schedule 3 (***RYD***=11.4% on the average, maximal ***RYD***=17.1% in 1955) and negligible with schedule 2 (average ***RYD*** =0.6%, maximal ***RYD***=4.6%). Referring to rainfed maize, the results indicate that coping with droughts and scarce water resources by adopting the less sensitive to water stress semi-early maize hybrids results in loosing up to half of yield potential (Fig.7).

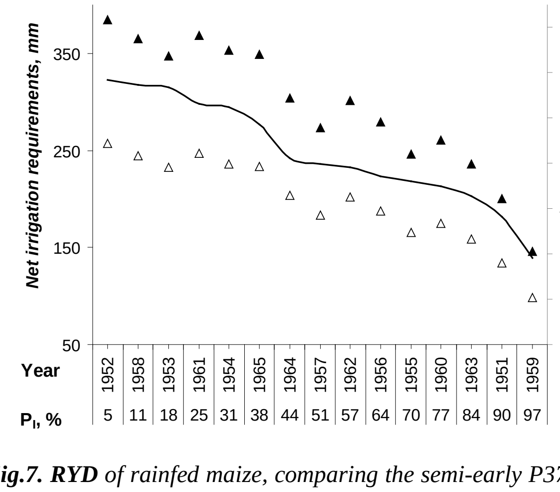


Fig.7. ***RYD*** *of rainfed maize, comparing the semi-early P37-37 (Δ),* ***Ky****=1.2, and late H708 (▲),* ***Ky****=1.6, hybrids,1951-1965 using all required climate daily data sorted in relation to probability of* ***NIR****.*

4. Conclusions: To assess how past (1951-1984) and present (1951-2004) weather conditions could affect irrigated maize crop in Varna region, simulations of several precise irrigation scheduling alternatives and a rainfed option were performed for a Haplic chernozem soil of medium water holding capacity. For the period of past climate 1951-1984 ***NIR*** ranges from 80 mm in the very wet 1959 to 150-210 mm in the average seasons ($40 \le P_I \le 75\%$) reaching 300 mm in the very dry 1952 (P_I=2%). ***NIR*** has increased by 30-35 mm in the average and high demand years having $P_I \le 75\%$ in the period 1951-2004. Simulations when using all required climate daily data show that rainfall is not fully used, particularly in the average years, because it falls during the earlier stages of the crop development, when irrigation demand is low and the soil water content is high. Adaptation of irrigation to changing climate consists of precise irrigation timing and demand evaluation for high and very high demand years, including planning the first irrigation event before conventional date. Application of irrigation scheduling alternative 2 leads to less impact on yield but requires 30-60 mm more irrigation water than the water saving alternatives 1 and 3.

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