DROUGHT VULNERABILITY OF BULGARIAN AGRICULTURE BASED ON MODEL SIMULATIONS

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Abstract: This study assesses the vulnerability of Bulgarian rainfed and irrigated agriculture to drought using the WINISAREG model. This model was previously calibrated and validated for maize on soils of small, medium and large water holding capacity (TAW) in various locations of Bulgaria. Simulations are performed for Plovdiv and Sofia. Results relative to Plovdiv show that in soils of large TAW (180 mm m^{-1}) net irrigation requirements (*NIRs)* range 0-40 mm in wet years and 350-380 mm in dry years. In soils of small TAW (116 mm m^{-1}), *NIRs* reach 440 mm in the very dry year. *NIRs* in Sofia are about 80 mm smaller. Rainfed maize is associated with great yield variability. Considering an economical relative yield decrease (RYD) threshold of 60 and 48% of the potential maize productivity in Plovdiv and Sofia, 32 % of years are risky when TAW=180 mm m^{-1} in Plovdiv, that is double than in Sofia.

Keywords: Drought vulnerability, ISAREG simulation model, SPI-index

Introduction

Drought is a protracted period of precipitation deficit that results in damages to a variety of ecosystems including agriculture and water supply (NDMC, 2006; Pereira et al., 2009; Dow, 2011). In the lowlands of South East Europe (SEE), including Bulgaria, drought is a recurrent phenomenon as proved by numerous local studies (Domonkos et al, 2001; Hlavinka et al., 2008; Slavov et al.,2004, Koleva and Alexandrov, 2008). The climate in the most part of Bulgaria is continental with semi-arid features. Plovdiv region (La 42°09' N, Lg 24o45' E, Alt 160m) in the Thracian Lowland, which is an important agricultural area, experiences the warmest and driest climate, while Sofia field (La 42°15' N, Lg25o45', Alt 555m) is one of the coolest and wettest agricultural region in this country. The soil in both regions has variable water holding capacity classified as small (total available water TAW=116 mm m^{-1}) for alluvial and luvisol soils, medium (TAW=136 mm m^{-1}) for cambisol, and large (TAW=180 mm m^{-1}) for vertisol soils.

A variety of standard indices exist to support operational drought definition (Pereira et al., 2009). Among them, the Standard Precipitation Index SPI is the mostly recommended index by many researchers and meteorological services. However some limitations of SPI and other indices have been recognized (Moreira et al., 2006; Pereira et al., 2010). In general these indices do not take into account drought impacts on economy, mainly relative to losses of crop yield and increased irrigation requirements.

Crop models, like WAVE (Vancloster et al., 1994), CERES (Jones and Kiniry, 1986; Gabriel et al., 1995; 1996) and ISAREG (Teixeira and Pereira, 1998; Pereira et al, 2003), are increasingly being used for analyses of risk assessment of drought consequences under maize and wheat in this country (Aleksandrov et al,1993; Popova et al., 1995; Popova et al, 2001; Popova and Kercheva, 2002; 2005; Popova and Pereira, 2008). In previous studies the WinISAREG model (Pereira et al, 2003), an irrigation scheduling simulation tool for simulating the soil water balance and evaluating the respective impacts on crop yields, was validated using independent data sets relative to long term experiment with early and late maize hybrids.

The objective of this study is to assess the vulnerability of rainfed/irrigated maize to drought at Plovdiv and Sofia fields, South Bulgaria, using the validated WinISAREG model and seasonal standard precipitation index SPI(2) for the period 1951-2004.

Material and Methods

Climate

The standard precipitation index SPI is a wide-spread indicator of droughts. SPI computed on the basis of 6, 3 and 2 months, SPI (6), SPI (3) and SPI (2), for Plovdiv, Sofia and Gorna Oriahovitsa were initially used as climate characteristics in this country over the period 1931-2004 by Kercheva (2004**)**.

A version of seasonal standard precipitation index SPI (Pereira et al., 2010), that is an average or sum of the index during periods of maize sensitivity to water stress, is used as crop specific drought indicator (Fig.1) in this study. The monthly values of SPI (6), SPI (3) and SPI (2) were computed using long-term (1951-2004) monthly precipitation data from Plovdiv and Sofia Central MTO stations - NIMH and Tsalapitsa field - ISSNP. Average SPI (2) for several periods referring to maize sensitivity to drought, such as the vegetation season “May-Aug”, the Peak Season “June-August”, and the High Peak Season “July-August” (Fig.1) were used to define categories of agricultural drought relative to summer crops in Sofia and Plovdiv region.

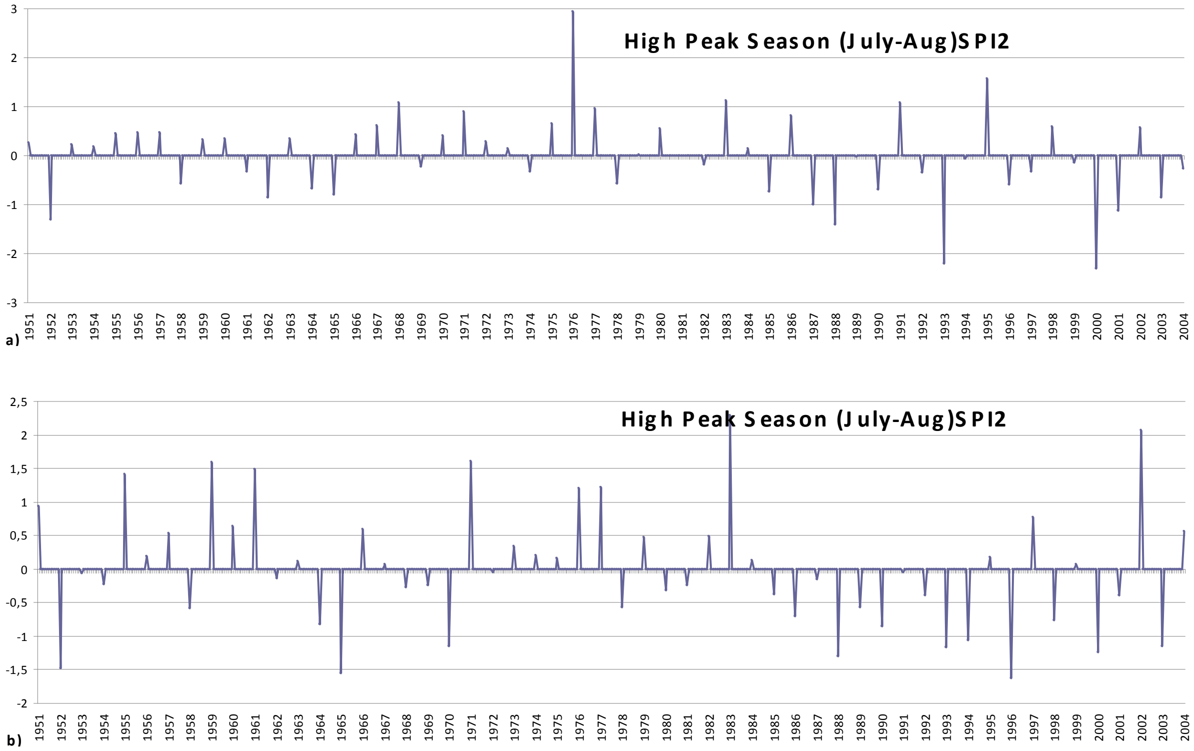


Fig. 1 *Evolution of High Peak Season (July-Aug) SPI (2) at: a) Sofia and b) Plovdiv, (Data from Central Climate Stations of NIMH, 1951-2004).*

The seasonal SPI (2) relative to “July-Aug” in Sofia field plotted in Fig. 1a indicate that irrigation season in 1993 and 2000 were the driest over the last 54 years. The high peak seasonal SPI (2) “July-Aug” in Fig. 1b also show that in the region of Plovdiv summer is become dryer over the last 20 years when compared with the previous 34 years.

Monthly precipitation for the average, wet and dry seasons, heaving probability of exceedance of precipitation P=50%, P=10% and P=90% are compared for Sofia and Plovdiv in Figs.2a and 2b.

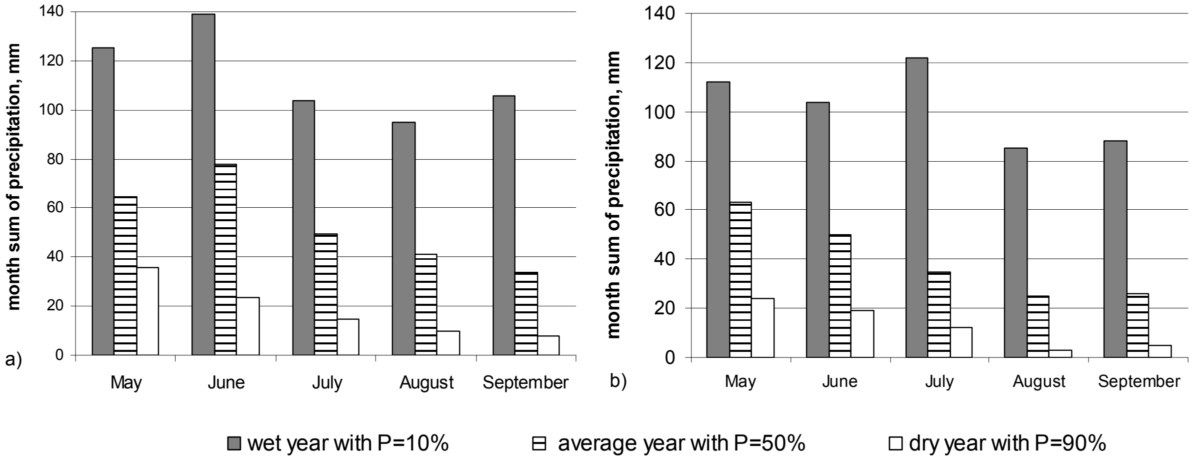


Fig. 2 *Average monthly precipitation for the average (probability of exceedance of precipitation P=50%), wet (P=10%) and dry (P=90%) seasons at: a) Sofia and b) Plovdiv Central Stations of NIMH, 1951-2004.*

The results indicate that monthly precipitation in Sofia field for June, July and August is about double when compared with those in Plovdiv.

Soil data

The study adopted formerly studied soil properties of Tsalapitsa, Zora and Bojurishte fields to determine the total available water in the root zone (TAW) for the alluvial and chromic luvisol, cambisol and vertisol soils of small, medium and large water holding capacity. Detailed data about soil texture, field capacity, wilting point and bulk density from several soil pits were used (Doneva, 1976; Varlev et al., 1994; Eneva, 1997; Popova et al, 2006, 2008, 2010). The study is carried out for three typical soil profiles with total available water (TAW) of 116, 136 and 180 mm m^{-1}.

Crop data

Maize was selected as the typical summer crop for the country. Detailed and good quality crop data from long term field experiments carried out in the Thracian lowland and Sofia field are available (see Varlev et al., 1994; Eneva, 1997; Varlev and Popova 1999; Stoichev, 1997; Alexandrova, 1990, Rafailov 1995; 1998; Jivkov, 1994; Mladenova and Varlev, 1997, Moteva, 2005 in Varlev, 2008). In our previous studies, crop coefficients *Kc* and the yield response factor *Ky* (Allen et al., 1998) were calibrated and validated using independent datasets relative to seven year experiments with a late maize variety H708 carried out under different irrigation schedules in Tsalapitsa, Plovdiv region (Popova and Pereira, 2010; 2011; Popova et al.,2011). In this study, additional data on rainfed maximum yields were used to adjust the yield response factor *Ky* to semi early maize hybrids for Sofia field (Jivkov, 1994; Mladenova and Varlev, 1997 in Varlev, 2008). The simulated yield decrease *RYD = 1-Ya/Ymax* was transferred to actual yield values (*Ya*) by using data on maximum yield (*Ymax*) relative to late and early maize hybrids (late: H708, 2Л602 and BC622; early: SK-4, SK-4BA, Px-20 P 37-37) observed in Sofia and Plovdiv regions over the period 1973-1991 (Stoyanov, 2008).

Simulation model

The WinISAREG model (Pereira et al., 2003) is an irrigation scheduling simulation tool for computing the soil water balance and evaluating the respective impacts on crop yields. The model adopts the water balance approach of Doorenbos & Pruitt (1977) and the updated methodology to compute crop evapotranspiration and irrigation requirements proposed by Allen et al. (1998). Yield impacts of water stress are assessed with the Stewart one-phase model when the yield response factor Ky is known (Doorenbos & Kassam, 1979). Crop coefficients *Kc* and yield response factors *Ky* for late maize hybrids were validated in previous studies (Popova et al., 2006, 2011; Popova and Pereira, 2010, 2011; Ivanova and Popova, 2011). The simulation options to compute net irrigation requirements *NIRs* and to execute the water balance without irrigation were used in this study. A specific ISAREG file was elaborated using previously validated soil and crop data. The soil data were representative for soils of small, medium and large water holding capacity (*TAW*) and crop data (mainly *Ky*) were additionally validated using independent data from local experiments with early and tardy maize hybrids.

Findings and discussions

Irrigation requirements, NIRs

Probability curves of maize net irrigation requirement (*NIRs, mm*) and rainfed maize yield decrease (*RYD, %*) for Sofia and Plovdiv regions were built using ISAREG model simulations over the period 1951-2004.

Net irrigation requirements of maize (NIRs) computed for the soils of small, medium and large water holding capacity (TAW) are presented in Figs.3a and 3b.

Results relative to Plovdiv show that in soils of large TAW (180 mm) net irrigation requirements (*NIRs)* range from 0-40 mm in wet years having probability of exceedance P_I>95% to 220-260 mm in average demand seasons (40%<P_I<75%) and reach 350-380 mm in very dry years (P_I<5%)(Fig.3b). In soils of small TAW (116 mm), *NIRs* reach 440 mm in the very dry year. *NIRs* in Sofia are about 80 mm smaller (Fig.3a).

Considering the trend of *NIRs* for the period under study, an average increase by 1.5 mm $year^{-1}$ i.e. 80mm over the whole period is found for Plovdiv; contrarily to irrigation requirements grain production of non-irrigated (late maize hybrid, H708) decreases by RYD=0.35% $year^{-1}$ on the average that is 19% for the period 1951-2004 (Fig.4).

Trends towards *NIRs* increase and yields decrease on drylands maize have not been found for Sofia field.

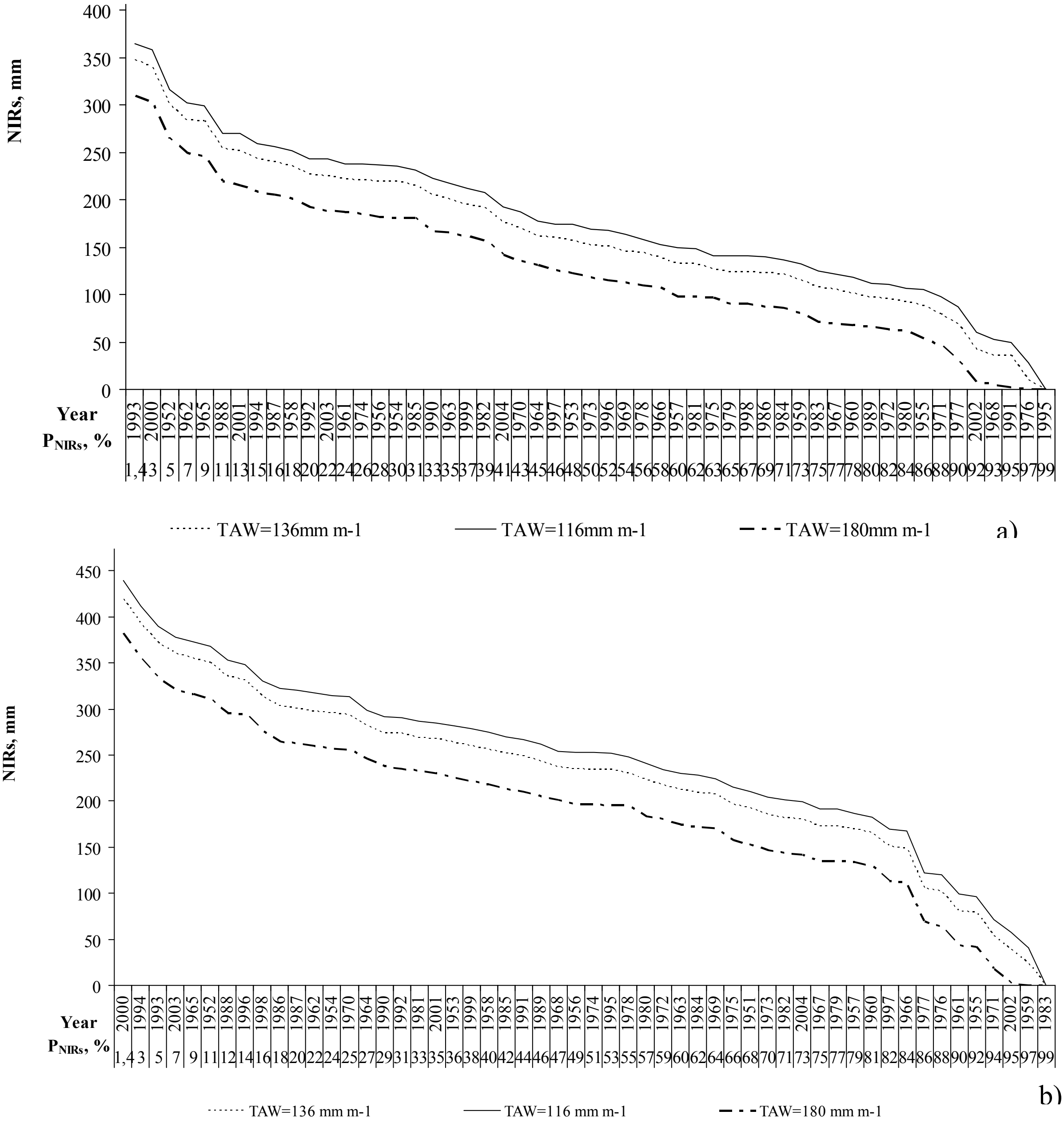


Fig. 3 *Net irrigation requirements (NIRs) probability of exceedance curves relative to soil of small, average and large water holding capacity (TAW) at: a) Sofia field and b) Plovdiv, Thracian lowland, 1951-2004.*

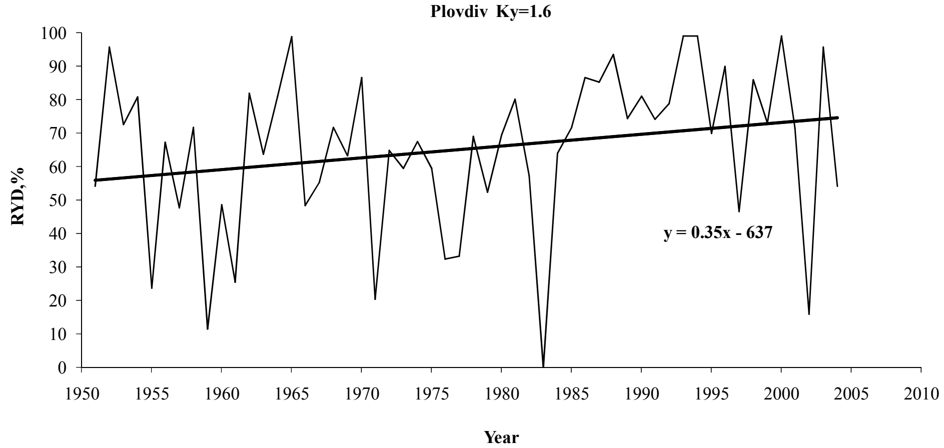


Fig. 4 *Relative yield decrease RYD for a rainfed late maize hybrid (H708), Ky=1.6, soil of TAW=116 mm* m^{-1}*, Plovdiv region, 1951-2004.*

Rainfed maize yield and risky years

Simulated relative yield decrease (*RYD, %*) with the yield response factor *Ky* = 1.6 and the option 'maize without irrigation' for soil of small water holding capacity (TAW=116 mm m^{-1}) at Sofia are sorted in a descending order in Fig.5. Additional *RYD* data from long-term experiments with semi-early maize hybrids conducted in Chelopechene field are plotted as well (see Jivkov,1994; Mladenova and Varlev, 1997 in Varlev, 2008). Comparing both *RYD* data series show that adopted *Ky* value in the model simulations take into account the sensitivity of semi-early maize variety to water stress under rainfed conditions in Sofia.

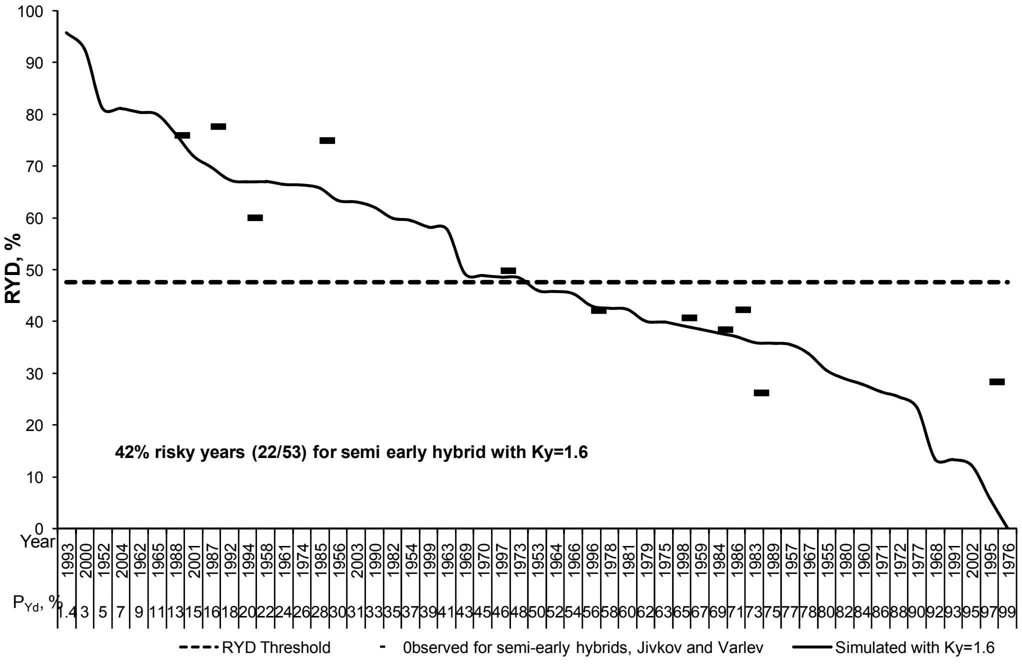


***Fig. 5** Probability of exceedance curve of relative yield decrease RYD under rainfed maize computed with Ky = 1.6 for soils of small (TAW = 116 mm m^{-1}) water holding capacity, Sofia field, 1951-2004.*

Similar analyses used to be performed for Tsalapitsa field, Plovdiv region, and the soil of small TAW (Popova et al, 2011) but using data relative to the late maize hybrid H708 (see Rafailov 1995; 1998;Varlev et al, 1994 in Varlev, 2008). Results show that a factor *Ky*=1.6 could reflect well the yield of rainfed maize there too. Figures 6a and 6b illustrate the derived "one to one" regressions between observed and simulated relative yield decrease RYD (%) with Ky=1.6 for the experimental sites in Tsalapitsa and Chelopechene. Derived regression coefficients (b=0.99 and b=0.95) and coefficients of determination (R^2=0.61 and R^2=0.82) indicate that yield response factor Ky=1.6 is statistically reliable to be used in the study.

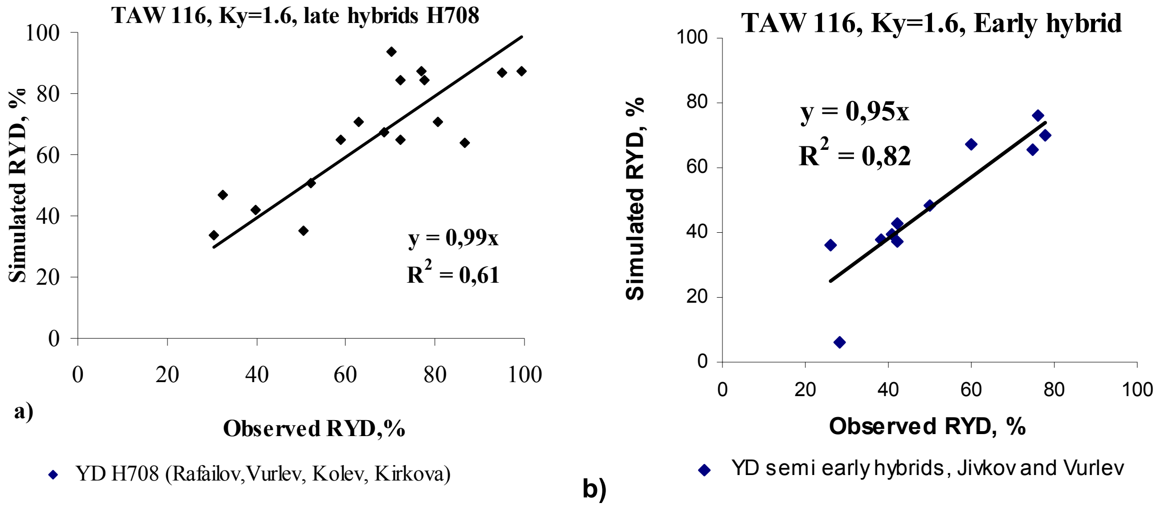
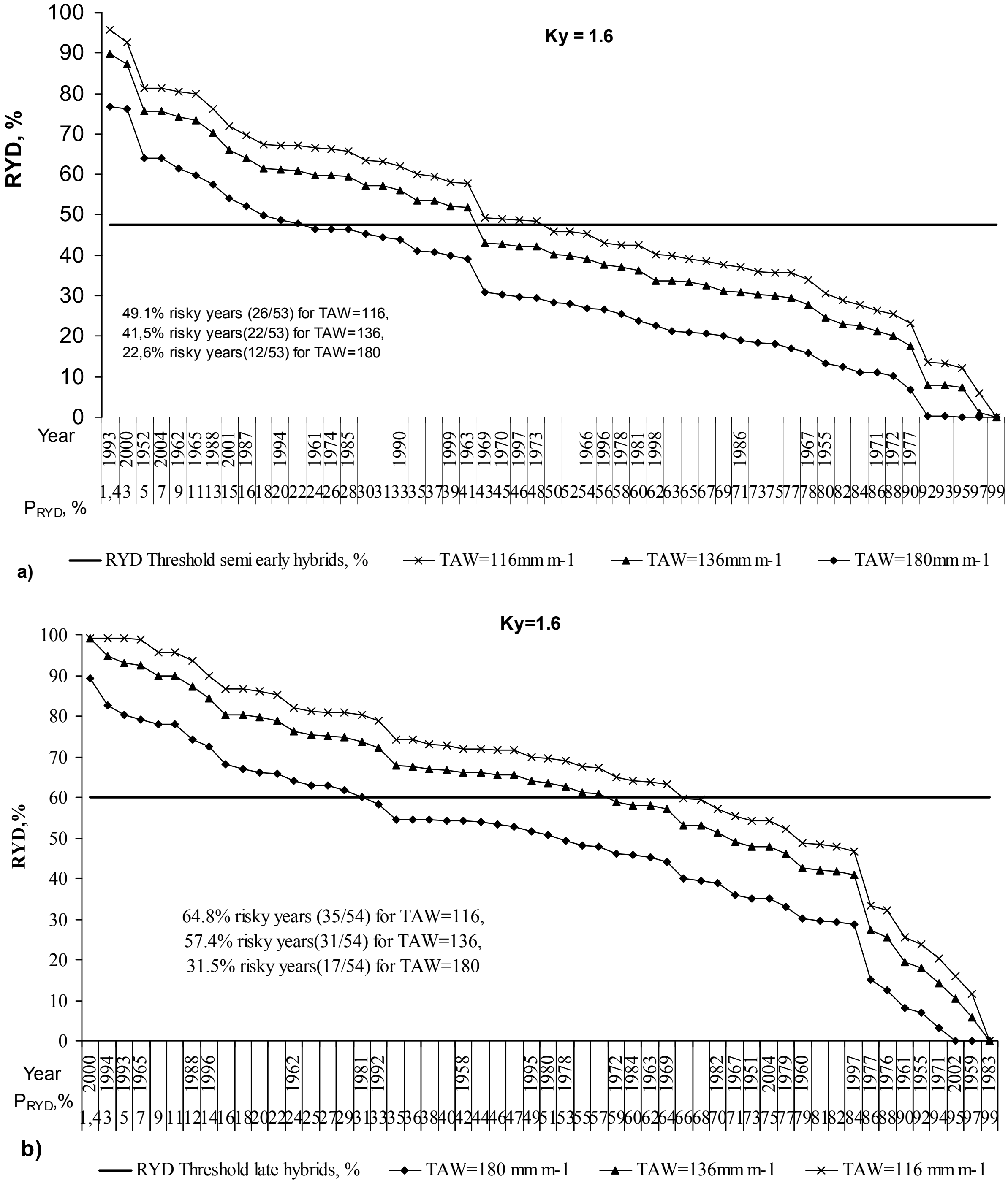


***Fig. 6** One to one regression between observed and simulated relative yield decrease RYD (%) with Ky=1.6 relative to: (a) Tsalapitsa, Plovdiv, and (b) Chelopechene, Sofia.*

The risky years relative to the soils of small, medium and large water holding capacity were identified using the probability of exceedance curves of computed relative yield decrease under rainfed maize with Ky=1.6 and the economical thresholds of RYD=48% for Sofia field (Fig. 7a) and RYD=60% for Plovdiv region (Fig. 7b).



49.1% risky years (26/53) for TAW=116,
41,5% risky years(22/53) for TAW=136,
22,6% risky years(12/53) for TAW=180

64.8% risky years (35/54) for TAW=116,
57.4% risky years(31/54) for TAW=136,
31.5% risky years(17/54) for TAW=180

Fig. 7 *Probability exceedance curves of relative yield decrease under rainfed maize RYD on the soil of small, medium and large water holding capacity TAW (116, 136, 180 mm m^{-1}), Ky=1.6, at: (a) Sofia for a semi early maize hybrid, and b) Plovdiv for a late maize hybrid (H708), 1951-2004.*

Both thresholds were found considering that maize cultivation is not profitable at a grain price 200 lv t^{-1} in Bulgaria (Varlev, 2002) when yields are below 4500 kg ha^{-1}. The economical threshold RYD=60% corresponds to the average potential yield under tardy maize hybrids (H708, 2Л-602 and BC622) with *Ymax* = 11 228 kg ha^{-1} in Tsalapitsa field, while the threshold RYD=48% refers to *Ymax* = 8460 kg ha^{-1} for semi-early maize hybrids (HD-225, SK-48A, Px-20, P37-37) in the field of Gorni Lozen, Sofia (Stoyanov, 2008).

It is found that 2/3 (65%) of the years are associated with economical losses on rainfed fields in Plovdiv (Fig. 7b) when the soil water holding capacity is small (116 mm m-1). Maize production suffers economical losses in half of the years when is considered the soil of *TAW* =136 mm m^{-1}. If soil water holding capacity is large (TAW=180 mm m^{-1}) economical risk refers to only 1/3 of the years. The risky years in Sofia field are 50, 42 and 23% respectively for soils of small, medium and large TAW (Fig.7a).

The specific thresholds of net irrigation requirements *NIRs,* 224 and 168 mm, were identified for conditions under which the soil moisture deficit leads to severe impacts on rainfed maize yield for soils of small *TAW* in both studied regions. The study shows that severe drought affect mostly the crop during the high sensitive periods of maize vegetation in 1993 and 2000, in Sofia field, These are linked to significant reduction of yields on rainfed maize with soils of small TAW (RYD>90%) (Fig.7a). Droughts in 2000, 1993, 1994 and 1965 led to a total loss of yield in Plovdiv.

Deriving of drought vulnerability categories

Seasonal SPI (2) were computed for crop specific sensitive periods important for maize yield formation and the whole season “May-Aug”, The Peak Season “June-August” and the High Peak Season “July-August” were related to respective simulated RYD of rainfed maize for soils of small, medium and large TAW in Plovdiv and Sofia (Fig.8). The relationships in Fig.8 were derived using climate data from NIMH-Central Plovdiv station.

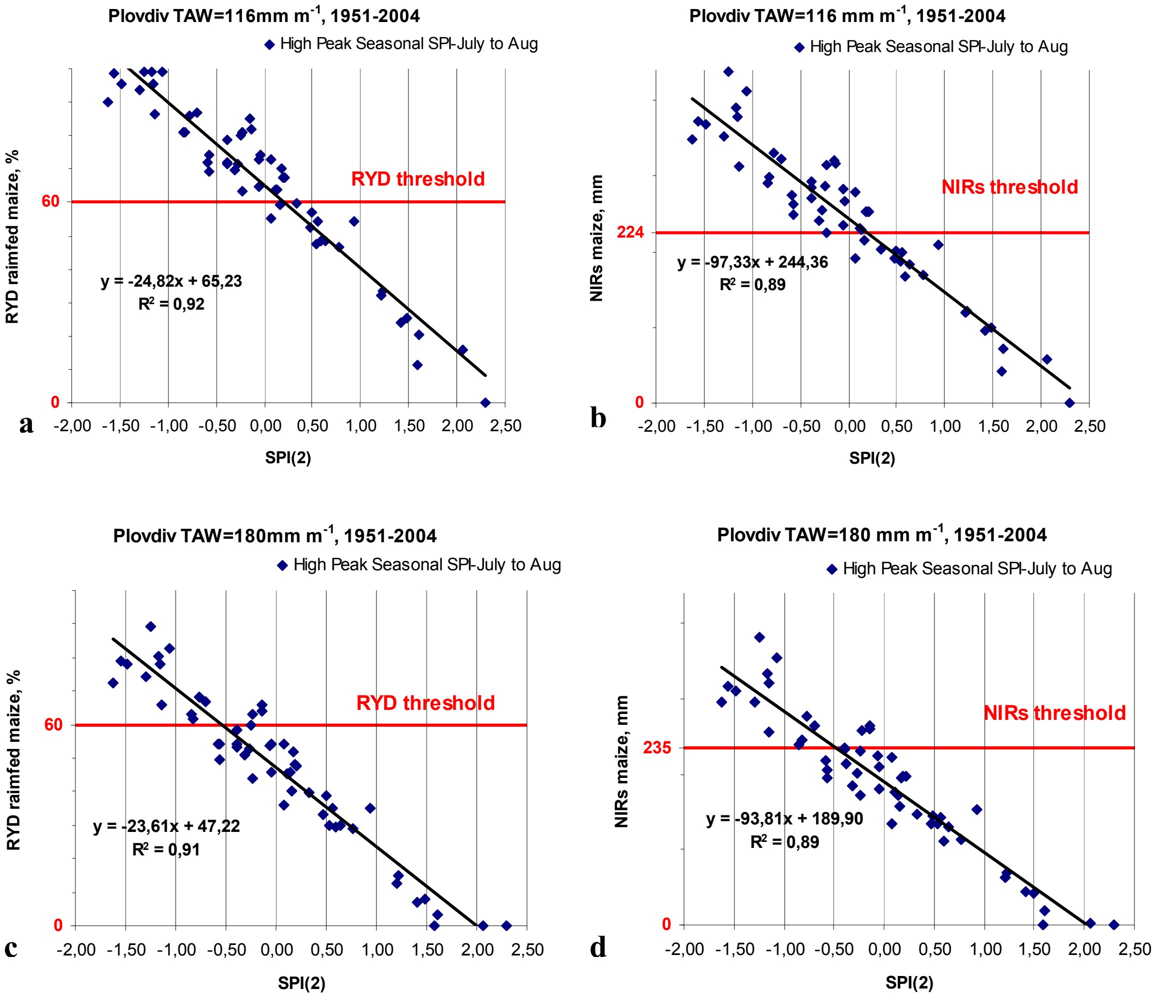


Fig. 8 *Relationships between seasonal SPI (2) “July-Aug” (X-axis) and relative yield decrease RYD for late maize hybrids Ky=1.6 (Y-axis), (a) and (c), or net irrigation requirements NIRs (Y-axis), (b) and (d). Risky years of RYD>60%, soil of small and large TAW (116 and 180 mm* m^{-1}*), Plovdiv.*

Soil specific threshold of seasonal SPI (2) “July-Aug” for soils of small, medium and large TAW were defined in Plovdiv region under which soil moisture deficit leads to severe impacts on rainfed maize productivity. Results indicate that farming maize without irrigation on soils of large TAW (180 mm m-^{1}) are less affected by seasonal water stress since unprofitable farming is produced when High Peak Season SPI (2)<-0.50 (Fig.8c). Corresponding NIR threshold of 235mm was identified (Fig. 8d).

When relating seasonal agricultural drought to the SPI (2) for “July-Aug” with simulated RYD in Sofia field, the derived relationships are less accurate (R^2>70%) (Figs.9a and 9c). It is found that when rainfed maize is grown on soils of large water holding capacity (TAW=180 mm m^{-1}) economical losses are produced when high peak season SPI (2) is smaller than -0.90 (Fig. 9c). The corresponding threshold of NIRs is 192mm (Fig. 9d).

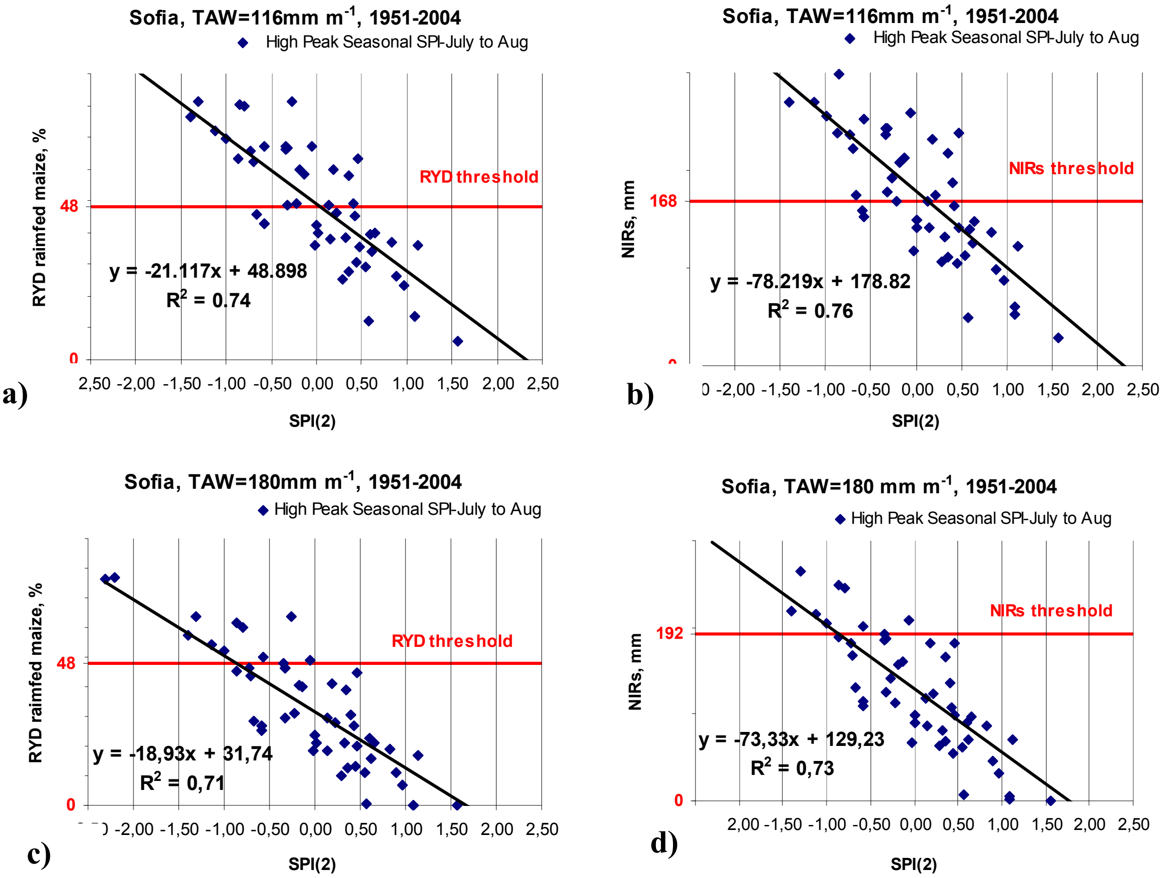


Fig. 9 *Relationships between seasonal SPI (2) "July-Aug" (X-axis) and relative yield decrease RYD for semi early maize hybrids Ky=1.6 (Y-axis), (a) and (c), or net irrigation requirements NIRs (Y-axis), (b) and (d). Risky years of RYD>48%, Sofia field, soil of small and large TAW (116 and 180 mm m^{-1}).*

Conclusions

The study relative to the period 1951-2004 in South Bulgaria shows that:

- On the soils of large *TAW* (180 mm) in Plovdiv region, the net irrigation requirements (*NIRs)* range from 0-40 mm in wet years. The NIR increase to 350-380 mm in the very dry years, when demand is only exceeded in 5% of the time. *NIRs* vary from 220 to 260 mm in average demand seasons (40%<P_I<75%). In soils of small TAW (116 mm) in the same region, the *NIRs* reach 440 mm in the very dry year. *NIRs* in Sofia are about 80 mm smaller.
- According to the detected trend in Plovdiv, *NIRs* have increased by 80 mm for the last period, corresponding to 1.5 mm year^{-1}; contrarily but consequently, the yield of rainfed maize has decreased by 19%, i.e. 0.35% year^{-1}. However there are no similar trends towards *NIRs* increase and yield decrease on drylands identified in Sofia field.
- Considering an economical yield threshold of 4500 kg grain ha^{-1}, the relative yield decrease threshold under which maize cultivation is not profitable in Plovdiv is RYD=60%. It was found that 2/3 of the years are associated with economical losses on rainfed fields when the soil water holding capacity is small (116 mm m-1). If soil water holding capacity is large (TAW=180 mm m^{-1}) only 1/3 of the years relate to economical risk. Differently, The risky years in Sofia are 50% and 23% respectively for soils of small and large TAW.
- In Plovdiv region reliable relationships (R^2 >91%) were found for seasonal agricultural drought relating the SPI (2) for "July-Aug" with the simulated relative yield decrease of rainfed maize (RYD). However, In Sofia the derived relationships are less accurate (R^2>71%).
- The study allowed to define soil specific threshold related with the seasonal SPI (2) "July-Aug" under which soil moisture deficit leads to severe impacts on maize yield. It is found that when rainfed maize is grown on soils of large water holding capacity (TAW=180 mm m^{-1}) economical losses are produced when high peak season SPI (2) < -0.50 in Plovdiv and SPI (2) < -0.80 in Sofia field. The corresponding NIR threshold was identified.

Acknowledgements

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