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DROUGHTS AND CLIMATE CHANGE IN BULGARIA: ASSESSING MAIZE CROP RISK AND IRRIGATION REQUIREMENTS IN RELATION TO SOIL AND CLIMATE REGION

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Abstract

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This study aims at assessing maize cropping risk due to observed trends for drought aggravation for the maize crop season which is associated with possible climate change trends relative to precipitation, temperature and reference evapotranspiration (ETo) at selected weather stations in Bulgaria. Water balance and relative yield computations were performed with the model WinISAREG after its calibration and validation for maize at various locations of Bulgaria and using long-term experimental data. Rainfed maize is associated with a great yield variability ($29 < C_v < 72\%$) due to inter-annual and spatial climatic variability during the maize season. The largest yields variability were found for Sandanski and Plovdiv when a soil with low total available water (*TAW* = 116 mm m^{-1}) is considered. The least variable yields are those for Sofia when TAW = 180 mm m^{-1}. Basing upon economic considerations, relative yield decreases (*RYD*) were computed with the threshold of 60 and 48% of the potential maize productivity in Plovdiv and Sofia. Maize production is risky in 32% of years in Plovdiv when *TAW* is large, which is the double of risk in Sofia. If *TAW* is medium the risky years double and reach 50% of years in Varna. A relationship between the SPI-2 index computed for "July-Aug" with the simulated *RYD* of rainfed maize was found. It is quite significant in Plovdiv where $R^2 > 91\%$ was found. Results are less good for Sandanski and Sofia ($73 < R^2 < 83\%$).

Results indicate that when rainfed maize is grown on soils of large *TAW*, maize development is less affected by the water stress. Economical losses are produced when high peak season (July-Aug) SPI-2 is less than +0.2 in Sandanski, -0.50 in Plovdiv and -0.90 in Sofia. In North Bulgaria the respective SPI threshold ranges between -0.75 at Lom and -1.5 at Pleven. When irrigation is considered, a relationship was also found relating the net irrigation requirements (NIRs) with SPI-2 "July-Aug". Consequently, the corresponding economic thresholds relative to the yield losses were computed for all locations this allowed to estimate the NIR thresholds that may lead to favourable cropping returns. The derived reliable relationships and related SPI-2 thresholds relative to "July-Aug", under which soil moisture deficits lead to severe impact of drought on rainfed maize yield for the studied climate regions and soil groups were used for mapping the risk of rainfed maize yield decreases as a function of drought intensity, which combined with maps relative to NIR to overcome drought effects on maize production.

Key words: Drought Intensity-Yield Relationships, Isareg Model, Net Irrigation Requirements, Rainfed Maize Vulnerability, Relative Yield Decrease, SPI-index

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Introduction and Objective

Climate uncertainty affects performance and management of agriculture. Extreme weather events, as drought, lead to substantial increase in agricultural risk and unstable farm incomes. The necessity to develop methodologies and simulation tools for better analysing, forecasting and managing the risk of agricultural drought is evident after the extremely dry 2000, 2007 and 2012 when the average maize grain yield in Bulgaria dropped to less than 1.8 t ha^{-1} (Statistical Yearbooks). The recent study by Olesen et al. (2011) on the impacts of climate change in European agriculture supports the hypothesis that Bulgarian agriculture is becoming more vulnerable to droughts and climate variability. This study shows that most negative effects are expected for the Pannonian zone – that includes Bulgaria, Hungary, Serbia, and Romania where increased heat waves and drought events are expected.

Guttman (1998) recommended the Standardized Precipitation Index, SPI (McKee et al., 1993; 1995) because it is standardized and contains a probabilistic interpretation, hence can be used in risk assessment and decision-making. Although analysing precipitation characteristics is fundamental when studying drought risk, if there is the need to perform comparisons among areas having different precipitation regimes or climate characteristics, adopting a standardized variable like the SPI is preferred to capture dryness and wetness conditions (Bordi et al., 2009).

In our recent studies trend tests were applied to monthly precipitation, maximum and minimum temperature and to the Standardized Precipitation Index with 2-month time step (SPI-2) relative to the period of 1951-2004. Negative trends were identified for precipitation and SPI-2 at various locations, mainly in the Thrace Plain, indicating that dryness is likely to be increasing in Bulgaria (Popova et al., 2013a; Popova et al., 2013b).

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 (Popova et al., 2006b; Popova, 2008; Popova and Pereira, 2011). Popova and Kercheva (2005) used the CERES models to assess impacts of drought on maize and wheat and identified the role of soil characteristics on those impacts. Popova and Pereira (2008) combined the use of the soil water balance model ISAREG with the Stewart's yield model (Stewart et al., 1977) to assess impacts of climate variability on irrigation scheduling and management in the Thrace Plain of Bulgaria.

This study aims at assessing maize cropping risk and supporting drought risk management due to observed trends for drought aggravation for the maize crop season, which is associated with negative trends relative to precipitation, air temperature and reference evapotranspiration (ETo) by application of the validated WinISAREG model and the SPI-2 index at selected locations of South and North Bulgaria.

Materials and Methods

Climate data and analyses

The study was performed for various locations in Bulgaria: Lom, Pleven, Silistra and Varna as to represent the northern regions, and Sofia, Plovdiv, Stara Zagora and Sandanski in the southern regions (Figure 1). Different climates are therefore considered: a moderate continental climate in Sofia, Pleven, Lom and Silistra, a transitional continental climate at Stara Zagora and Plovdiv, a northern Black Sea climate in Varna, and a transitional Mediterranean climate in Sandanski.

Monthly precipitation and reference evapotranspiration (ETo) relative to the period 1951 to 2004 at selected locations of northern and southern Bulgaria are presented in Figure 2. Precipitation represents wet, average and dry years, i.e., when the probability for being exceeded is respectively 10, 50 and 90%. The precipitation during the maize cropping season ("May-Sept") shows a great inter-annual variability and a non-negligible seasonality, with less precipitation during the months of July, August and September, when maize flowering and yield formation occur (Figures 2a, 2c, 2e and 2g). There is also an evident spatial variability, with larger precipitation in Sofia and the northern locations.

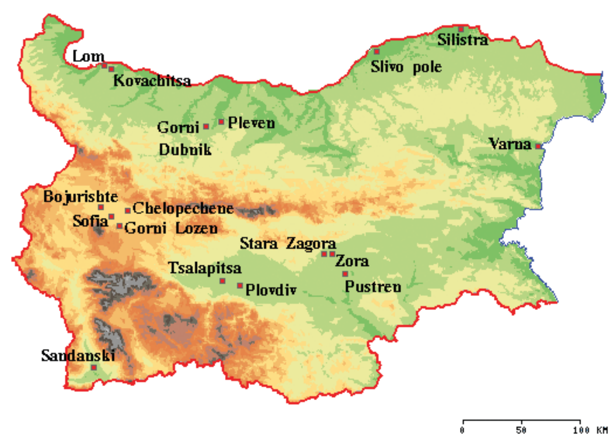

Fig. 1. Experimental fields of *ISSAPPNP* and meteorological stations of *NIMH* in Bulgaria

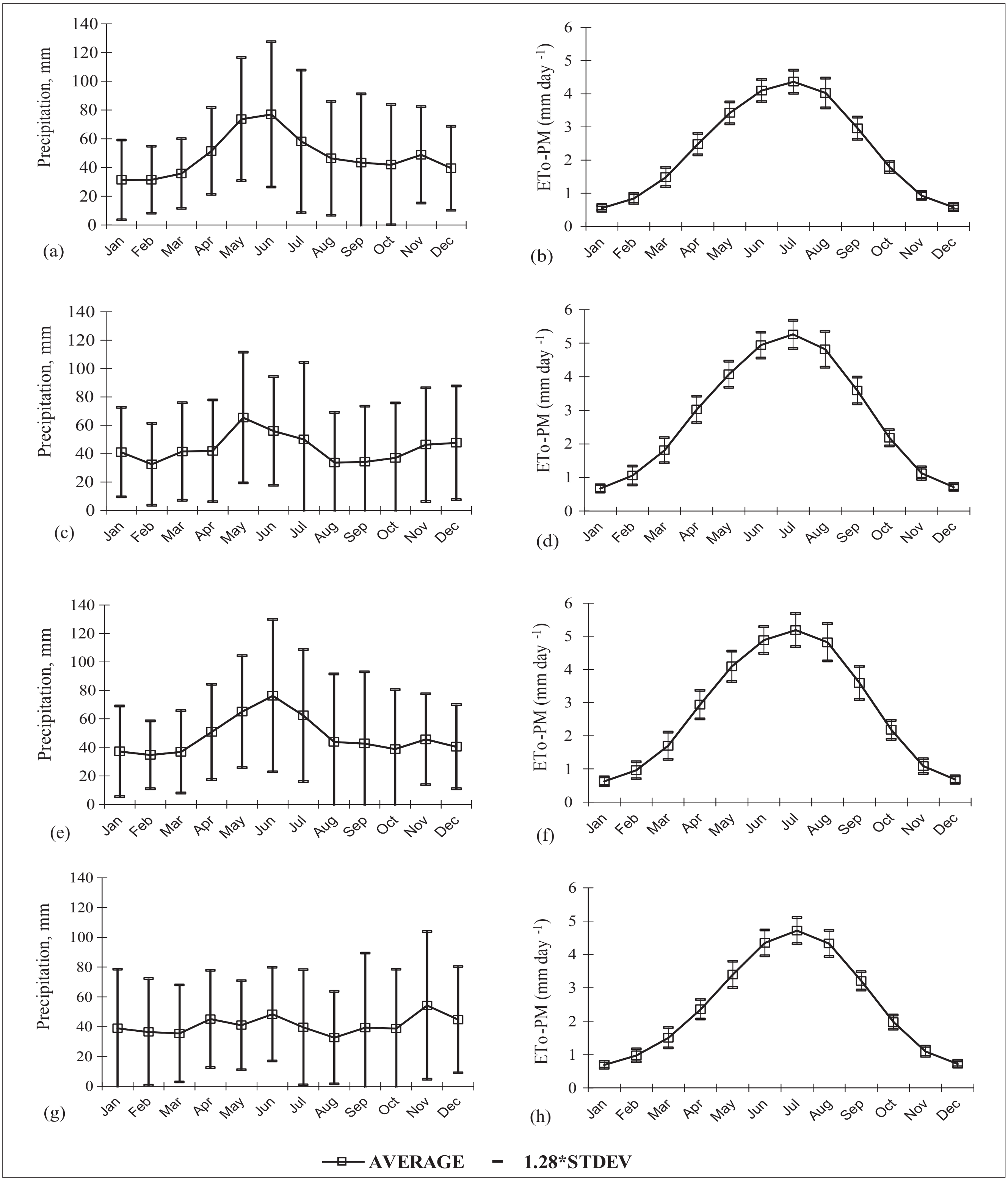

Fig. 2. Average monthly precipitation totals (mm) and reference evapotranspiration *ETo-PM* (mm day^{-1}) (□); bars represent the 80% confidence interval, 1951-2004; (a) and (b) Sofia; (c) and (d) Plovdiv; (e) and (f) Pleven; (g) and (h) Varna

ETo was computed with the PM-ETo equation (Allen et al., 1998) using only temperature data as described by Popova et al. (2006a). ETo refers to low, average and high climatic demand conditions, when ETo values are exceeded with a probability of 90, 50 and 10% respectively. ETo shows much less inter-annual variability than precipitation, as indicated by the bars representing the 80% confidence interval, and is higher in southern regions reaching 5.6 mm day^{-1} at Sandanski and 5.3 mm day^{-1} at Plovdiv and Stara Zagora (Figure 2d).

It drops to 4.9-4.3 mm day^{-1} in the northern locations of Lom, Silistra and Varna (Figure 2h). Peak Season ETo reaches minima of 4.4-4.0 mm day^{-1} in Sofia field (Figure 2b). ETo follows a regular seasonal distribution, with maxima in July and August when precipitation is smaller (Figure 2).

Probability curves of occurrence for seasonal precipitation and reference evapotranspiration ETo relative to the whole “May-Sept” season and the high demand “July-Aug” period are compared for six locations in Figures 3 and 4. The seasonal precipitation “May-Sept“are the highest and practically identical at Sofia and Pleven, varying between 120 and 600-700 mm (Figure 3a). As it may be observed comparing the probability curves in the figure, the curves for Sofia and Pleven are above all others that mean that the seasonal drought is expected to be mitigated there. Comparing the six

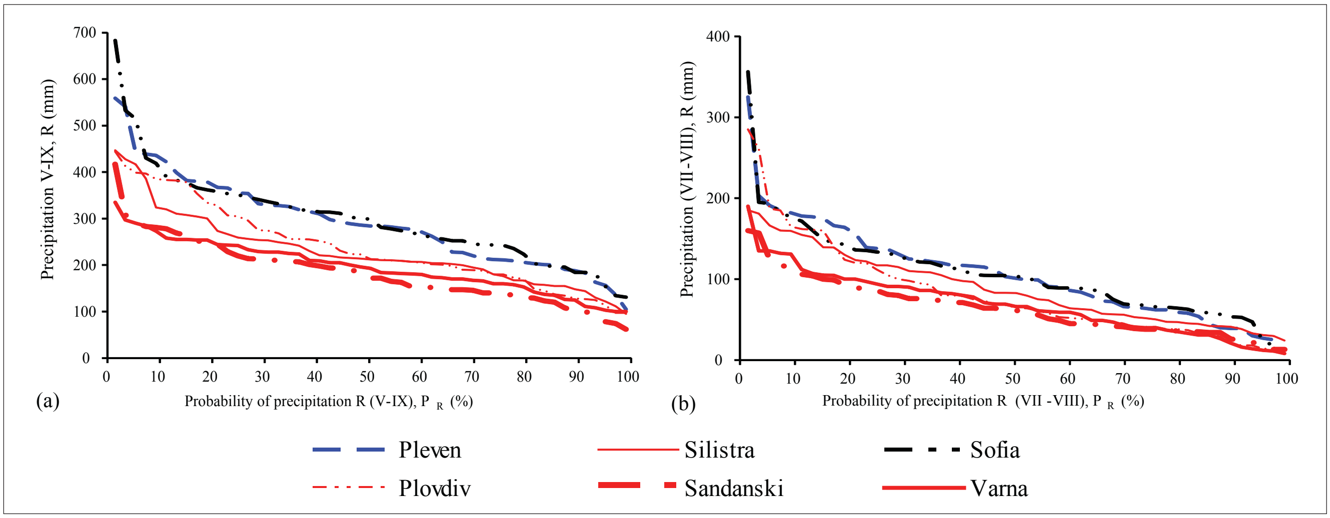

Fig. 3. Comparison of precipitation (mm) probability of exceedance curves for six climate regions relative to: a) Cropping Season (V-IX) and b) High Demand Season (VII-VIII), 1951-2004

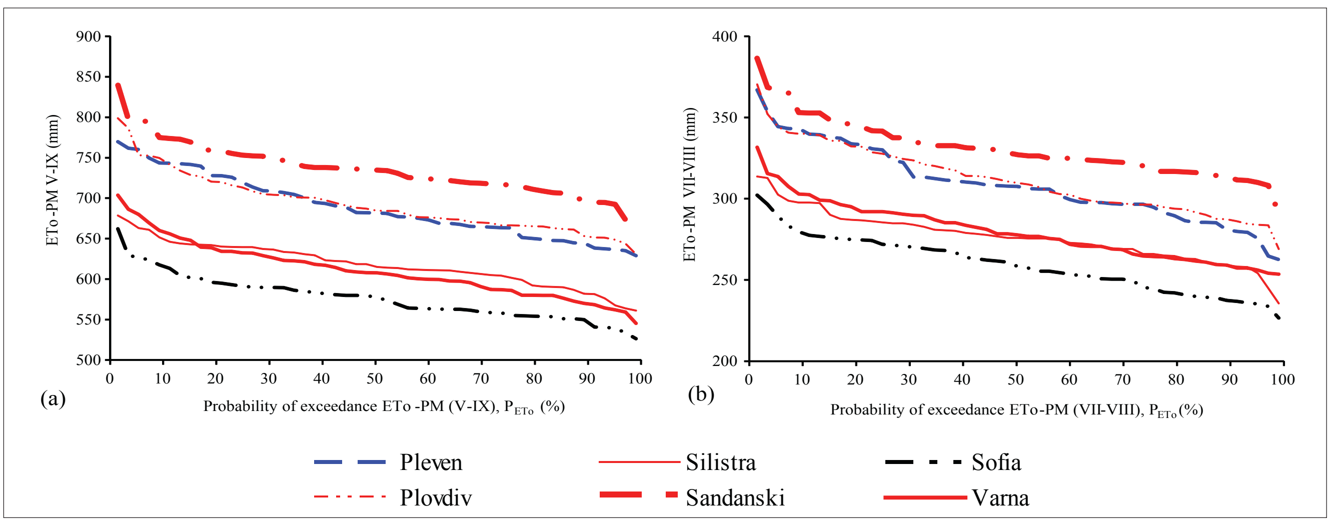

Fig. 4. Comparison of reference evapotranspiration *ETo-PM* (mm) probability of exceedance curves at six climate regions relative to: a) Cropping Season (V-IX) and b) High Demand Season (VII-VIII), 1951-2004

curves it may be concluded also that seasonal drought severity should increase for rainfed maize in the following order: Sofia, Pleven, Silistra, Plovdiv, Varna and Sandanski.

Regarding the peak demand period "July-Aug" differences in precipitation totals are about half of those related to the whole season (Figure 3b). However inter-regional differences become much smaller in the dry years (P > 90%) and augment over the average and wet years.

The inter-seasonal variability of reference evapotranspiration ETo-PM "May-Sept", compared with precipitation, is much lower (Figure 4). ETo-PM "May-Sept" is the largest in Sandanski (740 to 840 mm), about 110 mm less at Pleven and Plovdiv and the lowest in Sofia (Figure 4a). During the high demand season "July-Aug" the differences in ETo between locations are half than those relative to ETo "May-Sept" (Figure 4b).

Simulation soil water balance and yield model

Maize is one of the main summer crops in Bulgaria. During the period 1960-1990 it had been under irrigation over more than 100 000 ha. In the last 25 years however, regardless of the occurrence of severe droughts and dramatic yield losses referred above, maize is grown under rainfed conditions (Statistical Yearbooks). Crop parameters required for modelling consist of crop coefficients (Kc), water depletion fractions for no stress (p) and the water yield response factor (Ky), as defined by Allen et al. (1998). Crop parameters were obtained when calibrating the WinISAREG and Stewart's models using field data. The calibration and validation of the WinISAREG and the Stewart's models for Pustren and Zora (Stara Zagora), Tsalapitsa (Plovdiv) and Bojurishte (Sofia) were described respectively by Popova et al. (2006b), Popova (2008), Popova and Pereira (2011), Ivanova and Popova (2011) and Popova (2012). Calibration and validation of both models were performed using data relative to different irrigation management conditions and for rainfed maize (Eneva, 1997; Varlev et al., 1994; Varlev and Popova, 1999).

The WinISAREG model, described by Pereira et al. (2003) uses the soil water balance approach proposed by Doorenbos and Pruitt (1977) and the updated methodology proposed by Allen et al. (1998) to compute crop ET and irrigation requirements. Data required to perform the soil water balance with ISAREG 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 and wilting point for a soil depth of 1.0 m (Allen et al., 1998), and (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 model allows various simulation options including to simulate an irrigation schedule using selected irrigation thresholds, executing the water balance without irrigation, and computing the net irrigation requirements and others. Yield impacts of water stress are assessed with the Stewart's one-phase model [(1-Ya/Ymax) = Ky (1-ETa/ETmax)] (Stewart et al., 1977; Doorenbos and Kassam, 1979), whose Ky value of 1.6 was calibrated as referred in the above mentioned studies.

Monthly precipitation and ETo data series (1951 to 2004), with ETo computed as described by Popova et al. (2006a) are relative to the eight locations referred above.

Soil characteristics

Available soil water holding capacity values, herein the TAW values are relative to the three main soil groups occurring in the regions represented by each of the eight locations. TAW values were determined in former studies (Stoyanov, 2008; Boneva, 2012). In southern Bulgaria the most common soils are the Chromic Luvisols and Cambisols, that have predominantly medium TAW (136 mm m^{-1}), and Vertisols of large TAW ($170 \leq$ TAW ≤ 180 mm m^{-1}). In the plains of northern Bulgaria, TAW ranges from 157 to 180 mm m^{-1} in Chernozems soils or TAW > 170 mm m^{-1} in Vertisols. In the terraces along the rivers small TAW (≤ 116 mm m^{-1}) are found, which correspond to coarse-textured Luvisols and Fluvisoils - Soil map of Bulgaria (Koinov et al., 1998; Boneva, 2012).

Calibration/validation of crop parameters

Crop data originated from long term field experiments, mainly reported by Varlev et al. (1994), Eneva (1997) and Varlev and Popova (1999). The parameters Kc, p and Ky were those obtained from the above referred model calibration. The related parameterization and data on crop growth stages and root depths were extended to other locations using data obtained by Rafailov (1995 and 1998), Varlev (2008) and Stoyanov (2008), which referred to various maize hybrids (Popova, 2012; Popova et al., 2012),

Combining both the ISAREG and the Stewart's models, it was possible to estimate crop water and irrigation requirements and the yield impacts of water stress for each year of the series 1951-2004, i.e., the relative yield decrease (RYD) due to water stress. Computations were performed for all eight locations and using the available TAW data and for all years of the weather data series. It resulted three RYD series, one for each soil type – low, medium and high TAW - for each location. Empirical curves relating RYD with the probability of their occurrence (P_{RYD}) were therefore built. The corresponding net irrigation requirements (NIR) were also estimated for all of years of the series and related empirical probabilities of exceedance curves (P_{NIR}) were also built.

RYD thresholds representing the values when yields become insufficient to achieve a positive farm return were identified for all locations. Thresholds base upon the assumption that rainfed maize cultivation is profitable if the harvested yield is above 4500 kg; however, this value changes with production costs and commodity prices and needs to be updated for practical use. These thresholds varied from one location to another because potential yield productivity was different among all locations. For example, the RYD thresholds indicative of economic losses corresponds to 60% at Plovdiv and to 48% at Sofia: for Tsalapitsa, Plovdiv, the average potential yield for the period 1971-1991 using tardy maize hybrids (H708, 2L-602 and BC622) is Y_{max} = 11 228 kg ha^{-1} while for Gorni Lozen, Sofia, Y_{max} = 8460 kg ha^{-1} was observed for the same period with semi-early maize hybrids (HD-225, SK-48A, Px-20, P37-37).

Results and Discussions

Trends of aggravation of climate conditions during 1970-2004

Trend analyses were applied to climate data, mainly reference evapotranspiration (ETo) and precipitation, relative to selected weather stations. Results of the tests show that, relative to ETo for maize crop season (V-IX), a significant trend was observed for the period 1970-2004 (Figure 5).

The detected increase of seasonal ETo is 1.0 mm yr^{1} at Sofia and Silistra, up to 2.0-2.3 mm yr^{1} at Stara Zagora, Pleven, Lom and Sandanski and reaching a maximum of 2.6 mm yr^{1} at Plovdiv and Varna. In all stations the months of July and August contribute most for seasonal ETo increase (Table 1). If one considers the whole period (1951-2004), the magnitude of the trend is about half at Lom, Varna and Sandanski and only ¼ at Pleven and Plovdiv thus indicating that the aggravation of climate conditions is higher in recent times (Table 2).

Results relative to seasonal precipitation (V-IX) show that, contrarily to ETo, a significant inter-seasonal variability combined with a negative trend were observed for the recent 35 years. The magnitude of the trend ranges from -2.8 mm yr^{1} at Stara Zagora and Sofia to -2.3 mm yr^{1} (Silistra) and -1.8 mm yr^{1} (Pleven, Plovdiv) and reaching a minimum of -1.0 mm yr^{1} at Lom (Table 3). The detected trends in Peak

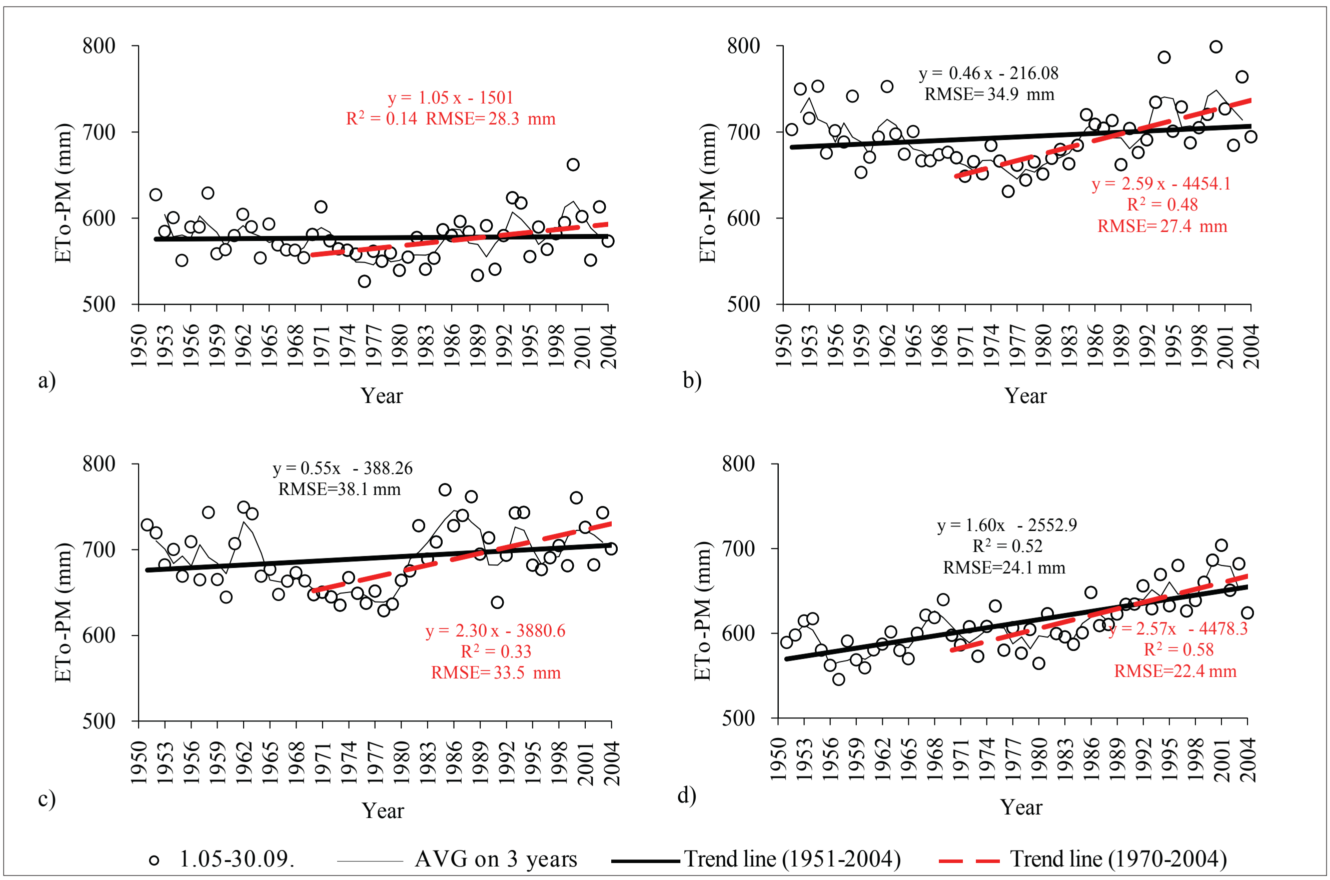

Fig. 5. Seasonal *ETo-PM* "May-September" (mm) (o) at:
a) Sofia; b) Plovdiv; c) Pleven and d) Varna; comparison of trendlines relative to 1951-2004 and 1970-2004

Demand season (VI-VIII) are responsible for the seasonal precipitation decrease (V-IX).

When the whole period (1951-2004) is considered, the magnitude of the trend for Peak season precipitation, com-

Table 1
ETo Trend Analysis (b refers to slope coefficient), 1970-2004

Periods	Seasonal ET_0 (V-IX)		Peak Season ET_0 (VI-VIII)		High Peak Season (VII-VIII)	
Stations	b, mm yr^{1}	ΣET_0, mm 35 yr^{1}	b, mm yr^{1}	ΣET_0, mm 35 yr^{1}	b, mm yr^{1}	ΣETcrop= KcΣET_0, mm 35 yr^{1}
Plovdiv	2.59	90.65	1.96	68.6	1.48	67.3
Pleven	2.30	80.5	1.83	64.05	1.43	65.1
Varna	2.57	89.95	1.78	62.3	1.31	59.6
Sandanski	2.37	82.95	1.78	62.3	1.30	59.2
Stara Zagora	1.90	66.5	1.57	54.95	1.26	57.3
Lom	2.27	79.45	1.67	58.45	1.24	56.4
Silistra	1.03	36.05	0.85	29.75	0.74	33.7
Sofia	1.05	36.75	0.86	30.1	0.70	31.9

Table 2
ETo Trend Analysis (b refers to slope coefficient), 1951-2004

Periods	Seasonal ET_0 (V-IX)		Peak Season ET_0 (VI-VIII)		High Peak Season (VII-VIII)	
Stations	b, mm yr^{1}	ΣET_0, mm 54 yr^{1}	b, mm yr^{1}	ΣET_0, mm 54 yr^{1}	b, mm yr^{1}	ΣETcrop= KcΣET_0, mm 54 yr^{1}
Plovdiv	0.46	24.84	0.36	19.44	0.17	11.9
Pleven	0.55	29.7	0.43	23.22	0.21	14.7
Varna	1.60	86.4	1.02	55.08	0.66	46.3
Sandanski	0.82	44.28	0.61	32.94	0.31	21.8
Stara Zagora	-0.05	-2.7	0.06	3.24	-0.06	-4.2
Lom	0.94	50.76	0.71	38.34	0.38	26.7
Silistra	0.81	43.74	0.55	29.7	0.36	25.3
Sofia	0.06	3.24	0.06	3.24	0.01	0.7

Table 3
Precipitation Trend Analysis (b refers to slope coefficient), 1970-2004

Periods	Seasonal R (V-IX)		Peak Season (VI-VIII)		High Peak Season (VII-VIII)	
Stations	b, mm yr^{1}	ΣR, mm 35 yr^{1}	b, mm yr^{1}	ΣR, mm 35 yr^{1}	b, mm yr^{1}	ΣR, mm 35 yr^{1}
Plovdiv	-1.84	-64.4	-1.48	-51.8	-1.04	-36.4
Pleven	-2.14	-74.9	-1.82	-63.7	-0.72	-25.2
Varna	1.70	59.5	0.33	11.55	0.52	18.2
Sandanski	-0.04	-1.4	-0.20	-7	-0.68	-23.8
Stara Zagora	-2.82	-98.7	-2.41	-84.35	-1.52	-53.2
Lom	-1.06	-37.1	-1.09	-38.15	0.09	3.2
Silistra	-2.29	-80.15	-1.79	-62.65	-1.29	-45.2
Sofia	-2.69	-94.15	-2.61	-91.35	-2.04	-71.4

paring with 1970-2004, is much smaller at Sofia, Stara Zagora, Pleven and Silistra (Figure 6a and 6c).

Globally the regions of Stara Zagora, Plovdiv, Sofia, Silistra and Pleven, with a decrease in peak season precipitation (VI-VIII) and an increase in evapotranspiration demands could have consequences in the occurrence of drought for summer crops in recent times (1970-2004).

Drought and climate impacts on yield and risky years

Results in Figure 7 refer to the empirical probability of exceedance curves of the relative yield decrease at Plovdiv and Pleven, respectively in southern and northern Bulgaria, where RYD is affected by the soil water holding capacity, considering the late maize hybrids H708, 2L602, BC622. Results in Fig.7a indicate that when soils have low water holding capacity, as 116 mm m^{-1}, rainfed maize yields are not only affected by droughts but also by climate variability. When comparing Figures 7a and 7b, it becomes evident that the vulnerability is much higher for southern (Plovdiv) than for northern locations (Pleven). Moreover, both figures show that cultivation in soils with high TAW (180 mm m^{-1}) leads to much less RYD relative to soils with low TAW.

The economical RYD thresholds for Pleven and Plovdiv are 67 and 60% respectively, correspond to the average yield potential for the period 1971-1991 of Y_{max} = 13 790 kg ha^{-1} at Pleven and Y_{max} = 11 230 kg ha^{-1} at Plovdiv. For Pleven, the RYD threshold refers to only 12% of years if a soil with high TAW is considered, and to 30% of the years when maize is cropped in a soil with low TAW (Figure 7b). Differently, for Plovdiv the threshold corresponds to 30 and 68% of the years, respectively (Figure 7a). These examples clearly show the combined effects of climate and soil type.

The empirical probability of exceedance curves of RYD relative to six climate regions - Silistra, Pleven and Varna in northern Bulgaria, and Sofia, Plovdiv and Sandanski in South - are compared in Figure 8a for rainfed maize cultivated in soils of medium TAW (136 to 157 mm m^{-1}). In Figure 8b the probability curves for the same locations are com-

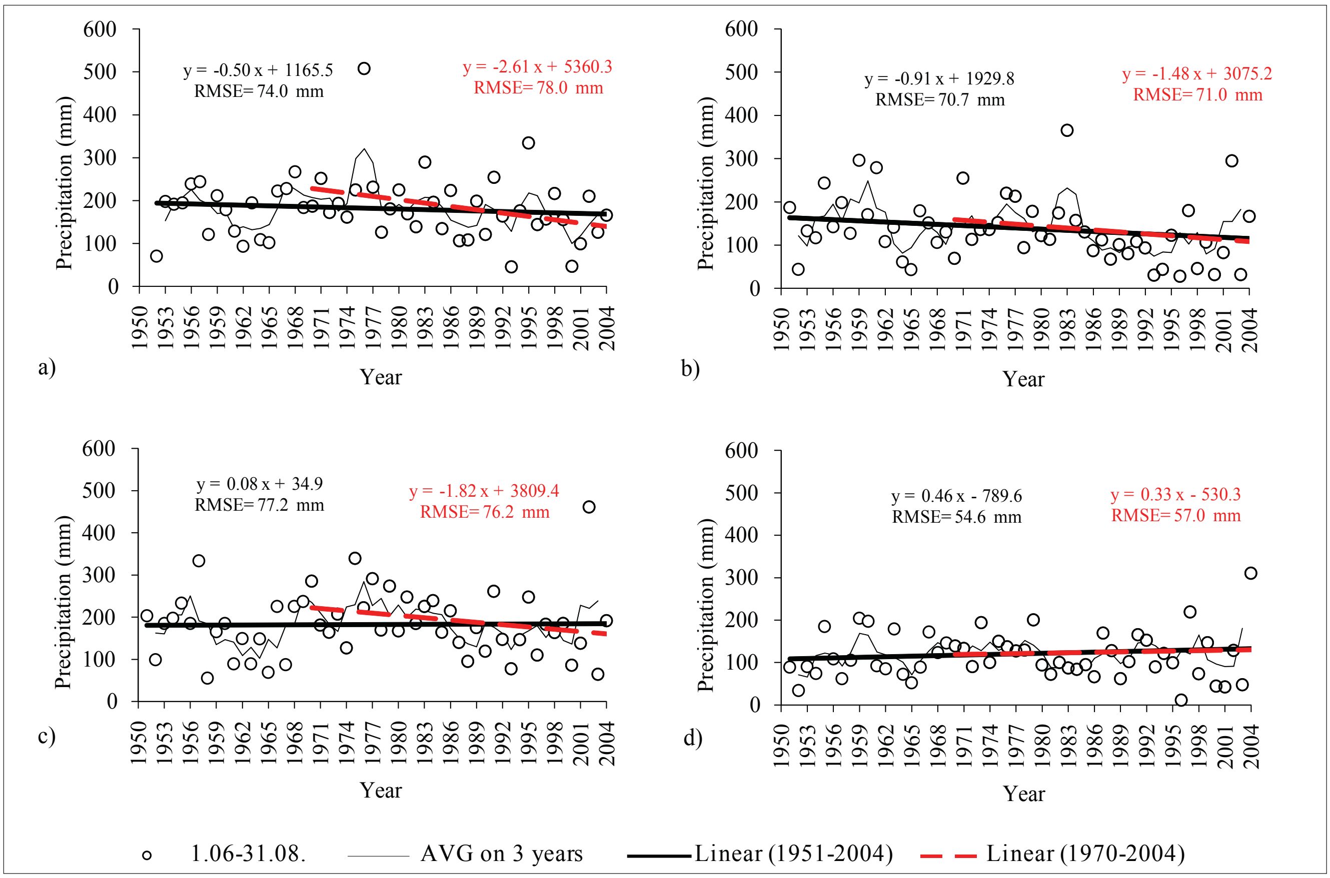

Fig. 6. Precipitation total for peak demand period "June-August" (mm) (o) at a) Sofia; b) Plovdiv; c) Pleven and d) Varna; comparison of trendlines for 1951-2004 and 1970-2004

pared when the soil has a large TAW. It can be noticed that the northern locations have the respective probability curves grouped below the Plovdiv and Sandanski curves, while Sofia behaves differently of other southern locations and the respective curve is the lowest because precipitation is higher there. Consequently the vulnerability to droughts and climate variability is smaller there. The RYD curve for Sandanski is above all others, which means that vulnerability is highest in this southern region where climate approaches the Mediterranean climate.

As it may be observed comparing Figure 8a and 8b, the relative position of the empirical probability curves is the same for soils with medium and high TAW. The difference is that RYD increase when soil TAW decreases. Comparing all six RYD curves, it may be concluded that the vulnerability increases in the following order: Sofia, Pleven, Silistra, Varna, Plovdiv and Sandanski thus indicating that the increase of vulnerability depends mainly upon the amount of precipitation during the maize crop season (Figure 3).

When TAW = 180 mm m^{-1} only 10% of the years are at risk of economic losses at Pleven and Silistra. When TAW is medium (157 mm m^{-1}) the risky years are 18 and 35% in those two sites and reach 50% in Varna (Figure 8b).

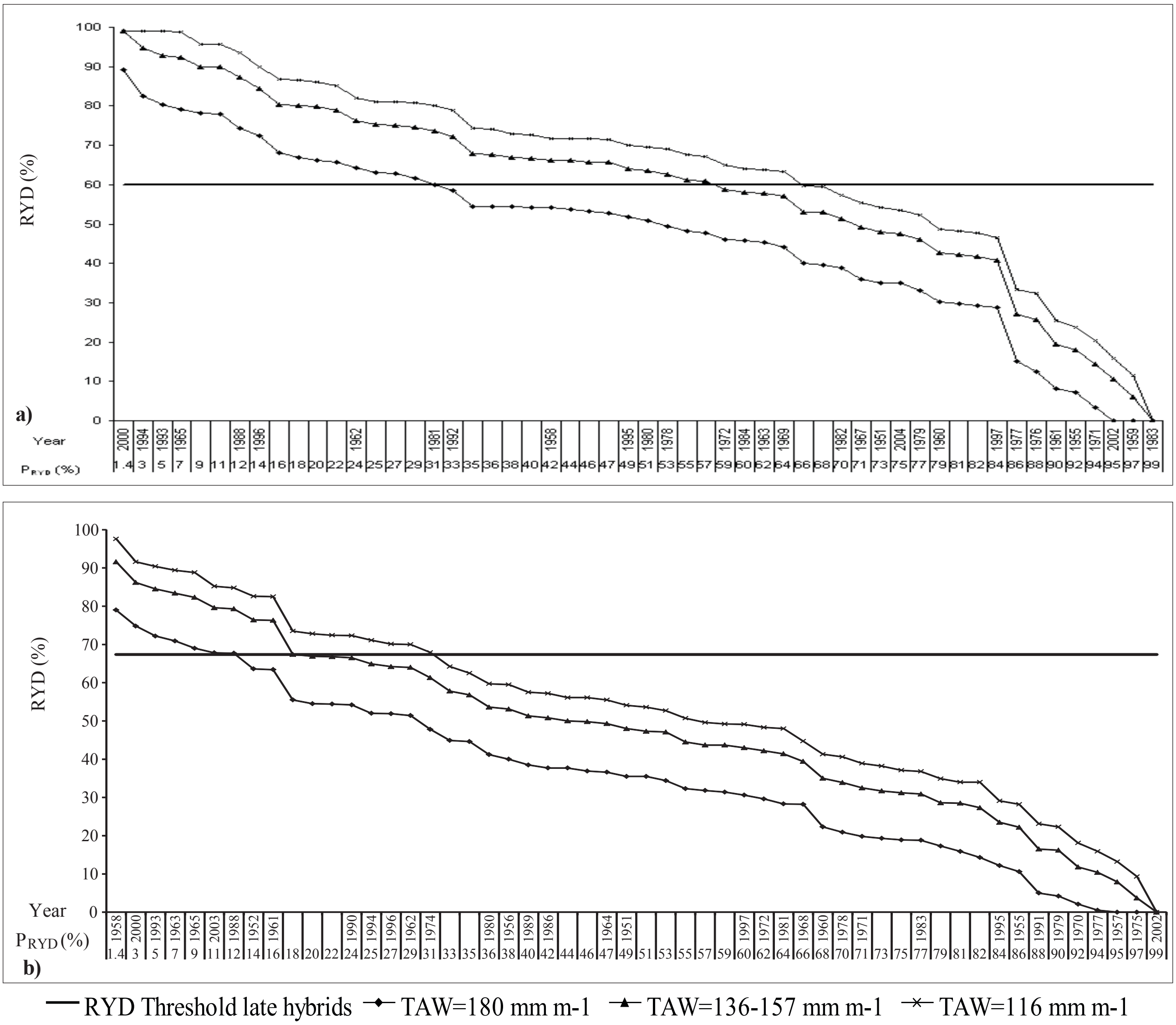

Fig. 7. Probability of exceedance curves of relative yield decrease RYD (%) for rainfed maize comparing soil groups of small, medium and large total available water (TAW) at:
a) Plovdiv, South Bulgaria; b) Pleven, North Bulgaria, Ky=1.6, 1951-2004

However, the RYD threshold values need to be updated every year to reflect the actual economic farming conditions and commodity prices.

As referred above the RYD threshold is the value when yield becomes insufficient to achieve a positive farm return. Thus, relationships between the yield threshold values У (t ha^{-1}) and the grain price G (BGN t^{-1}) are derived at different levels of production expenses PE (BGN ha^{-1}), as shown in Figure 9a. Since the grain price G ranges predominantly between 200 and 400 BGN t^{-1} over the last 20 years, the yield threshold values vary between 2 and 5.5 t ha^{-1} (Figure 9a). When the yield threshold values are expressed in relative terms, as RYD or [y = У/Уmax = 1-RYD], relationships are universal and could be compared for the main agro-climatic regions and the different levels of PE (BGN ha^{-1}) (Figure 9b and 9c).

Rainfed maize is associated with great yield variability with the coefficient of variation relative to 1951-2004 in the range 29 < Cv < 72% (Table 4). The coefficient of variability ranges 29-42% in Sofia, with Cv = 29% for soils with larger TAW. Higher Cv are for the other southern regions, namely in Sandanski (Cv = 72%), Plovdiv (Cv = 69%) and Stara Zagora (Cv = 59%). The variability of rainfed maize in the Danube Plain (Pleven, Varna and Silistra) is much lower than in the Thracian Lowland. However, in the region of Lom the yield variability is also high (35 < Cv < 55%).

Irrigation requirements in relation to climate and soil characteristics

Probability of exceedance curves of net irrigation requirement (NIR, mm) for maize were built using WinISAREG over the period 1951-2004 (Popova, 2012; Popova et al., 2012; 2013a). Results relative to Pleven (Figure 10a) show that for soils of large TAW (180 mm) NIR vary 0 mm in wet years, i.e., when the probability of exceeding is $P_{NIR} > 95\%$, 80-180 mm in average demand years ($40\% < P_{NIR} < 75\%$), and 300-330 mm in very dry years ($P_{NIR} < 5\%$). In soils with medium TAW (157 mm), NIR increase and reach 370 mm in the very dry year. Differently, NIR in Plovdiv and Stara Zagora (Figure 10b) are about 100 mm larger than in Pleven, while in Sandanski NIR are about 210 mm higher.

Trend analyses of yields and irrigation requirements

An empirical trend analysis was performed for both RYD and NIR (Figures 11 and 12) which shows that they both may increase for the last years of the observation period (1951-2004). Then, RYD for Plovdiv region may increase by 0.35% year^{-1} or a decrease of about 40 kg ha^{-1} year^{-1} may be expected if irrigation is not applied (the black trendline, Figure 11b). Similarly, RYD for the region of Stara Zagora may increase by 0.14% year^{-1} (or a decrease by 15 kg ha^{-1} year^{-1}results not shown). However, significant trends were not found for other regions and further analyses are required. If one considers

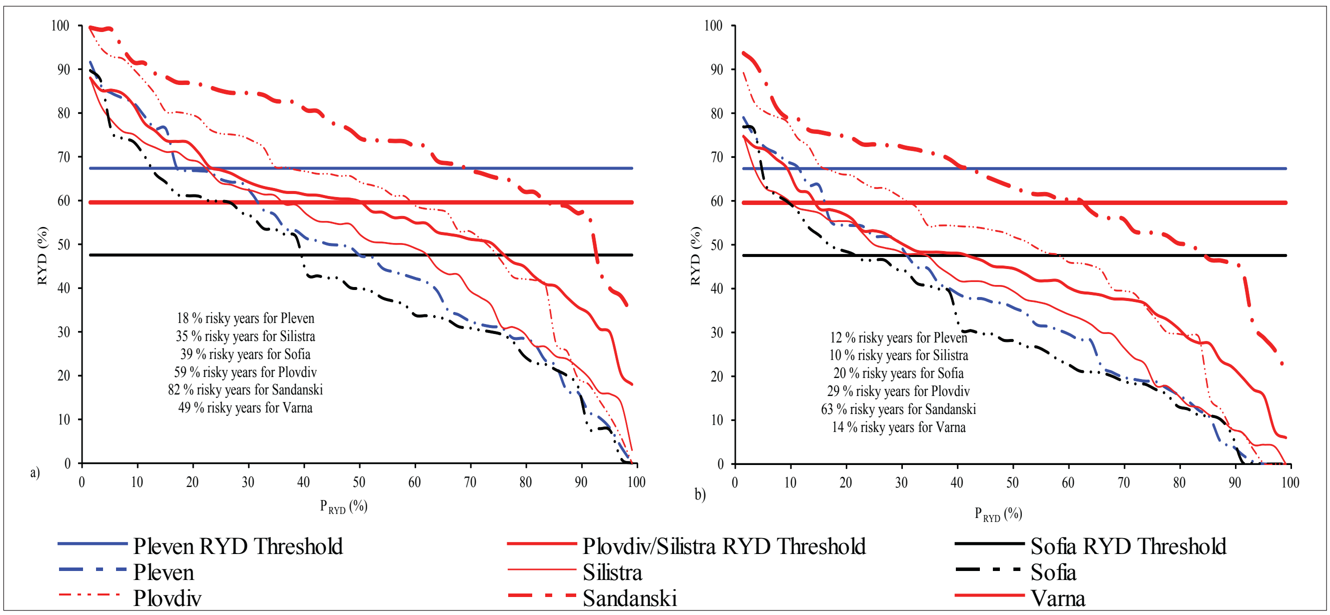

Fig. 8. Comparison of relative yield decrease (RYD, %) probability of exceedance curves, Ky = 1.6, relative to six climate regions and two soil groups of:
a) medium TAW (136-157 mm m^{-1}) and b) large TAW (180 mm m^{-1}) rainfed maize, 1951-2004

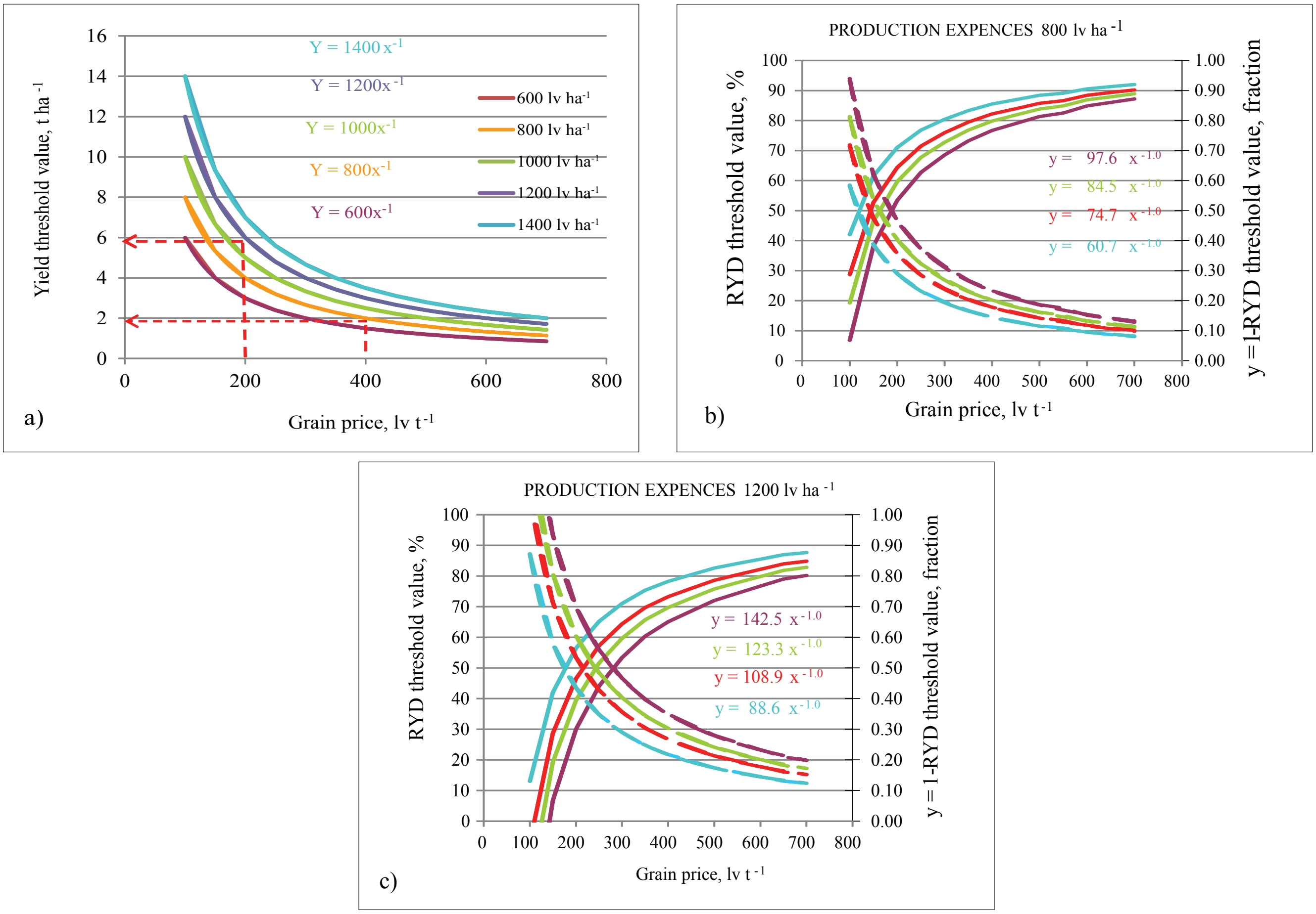

Fig. 9. Relationships between yield threshold values and grain price G (BGN t^{-1}) at different levels of production expenses PE (BGN ha^{-1}) when yield is expressed in absolute terms Y ($t\ ha^{-1}$) (a) or in relative terms, as relative yield decrease RYD (%) (b) or a fraction y=Y/Ymax=1-RYD (c)

Table 4
Variability of rainfed maize grain yield characterized by the mean value, $kg\cdot ha^{-1}$, and the coefficient of variation Cv, %, for the considered climate regions and soil groups in Bulgaria, 1951-2004

		South Bulgaria								North Bulgaria							
Climate region		**Moderate Continental**		**Transitional Continental**				**Transitional Mediterranean**		**Moderate Continental**						**North Black Sea**	
		Sofia Field		**Thracian Lowland**				**Sandanski**		**Danube Plain**							
Location		Sofia		Plovdiv		Stara Zagora		Sandanski		Pleven		Lom		Silistra		Varna	
Maize hybrid		semi early (HD-225, SK-48A, Px-20, P37-37)						Late *(H708, 2L602, BC622)*									
TAW ($mm\cdot m^{-1}$)		mean ($kg\cdot ha^{-1}$)	C_v (%)	mean ($kg\cdot ha^{-1}$)	C_v (%)	mean ($kg\cdot ha^{-1}$)	C_v (%)	mean ($kg\cdot ha^{-1}$)	C_v (%)	mean ($kg\cdot ha^{-1}$)	C_v (%)	mean ($kg\cdot ha^{-1}$)	C_v (%)	mean ($kg\cdot ha^{-1}$)	C_v (%)	mean ($kg\cdot ha^{-1}$)	C_v (%)
Small	116	4421	42	3894	69	3723	59	2292	72	6419	50	4187	55	4866	46	4349	50
Medium	136	4920	37	4550	59	4299	52	2906	59	7237	44	4827	47	5616	40	5156	42
	180	5896	29	5915	43			4250	41	8867	34	6094	35	7118	30	6810	30
Large	173					5483	41										

the present observation period 1970-2004 the magnitude of the trend, comparing with 1951-2004, is double in the Thrace (red dashed line, Figure 11b). Moreover, the maximum RYD increase (by 0.90% year^{-1}) is found not only for the southern (Stara Zagora) but also for the northern (Pleven) regions (Figure 11c), where a decrease of 100-120 kg ha^{-1} year^{-1}, or 4.2 t ha^{-1}, may be expected thus indicating that the aggravation of climate conditions in recent times is related to important economic losses for the rainfed maize crop system. The detected trend is also substantial (0.60-0.65% yr^{-1}) at Sofia, Silistra and Lom being half than in Pleven when expressed in kg ha^{-1} yr^{-1} (Figures 11a and 11d).

Trend test application to net irrigation requirements NIR for Plovdiv region and 1951 to 2004 shows an increase by 1.5 mm year^{1}, i.e. 80 mm in 54 years (Figures 12b). For the region of Stara Zagora NIR increase by 0.5 mm year^{1}, i.e. 27 mm. Relative to the present observation period 1970-2004, the trend analyses show that NIR may increase by 3.5 (Plovdiv, Pleven) to 4.0 mm year^{1} (Stara Zagora), i.e. by 120-140 mm 35 years^{-1}, and by 2.5 mm year^{1}, i.e. 90 mm 35 years^{-1}, at Sofia (Figures 12a), Lom and Silistra that is double than in Varna (results not shown).

The results indicate that due to the detected climate change impacts, compared to the available irrigation scheduling estimation in references (Zahariev et al, 1986), not less

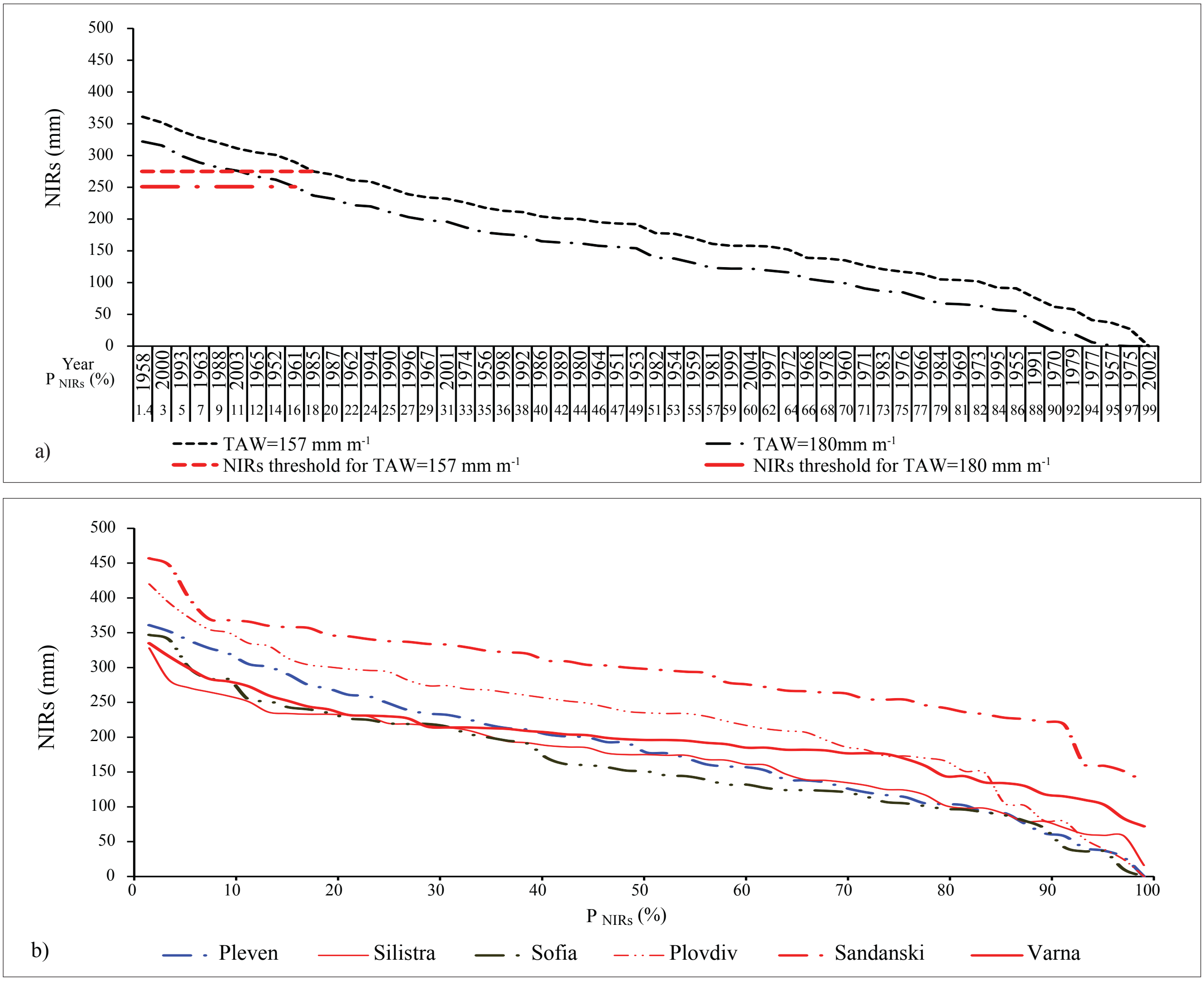

Fig. 10. Probability of exceedance curves for net irrigation requirements (NIRs, mm): a) at Pleven region as influenced by soil total available water TAW and b) for climate regions and soils of medium water holding capacity (TAW= 136-157 mm m^{-1}), 1951-2004

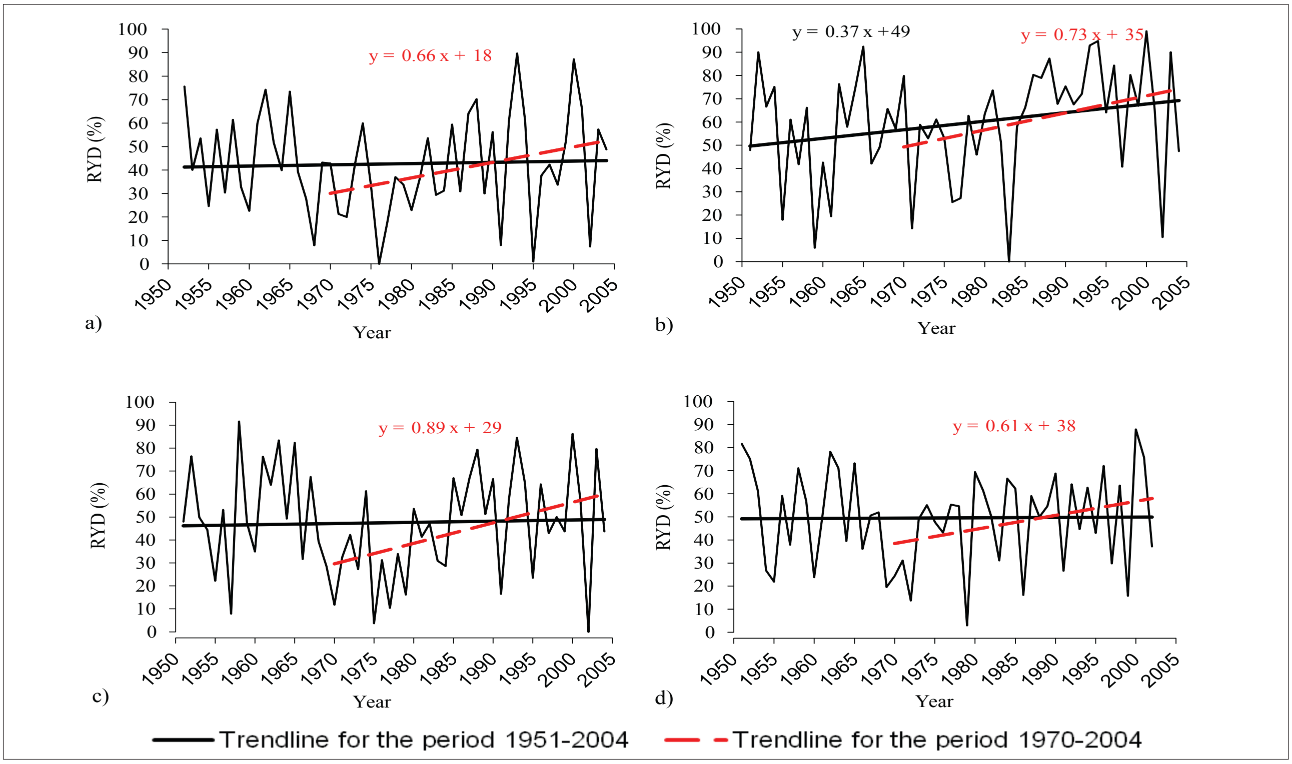

Fig. 11. Trendline of relative yield decrease RYD,%, for rainfed maize at: a) Sofia; b) Plovdiv; c) Pleven; d) Silistra; late hybrids (H708, 2L-602 and BC622), soils of medium water holding capacity (TAW=136-157 mm·m^{-1}), 1951-2004 vs. 1970-2004

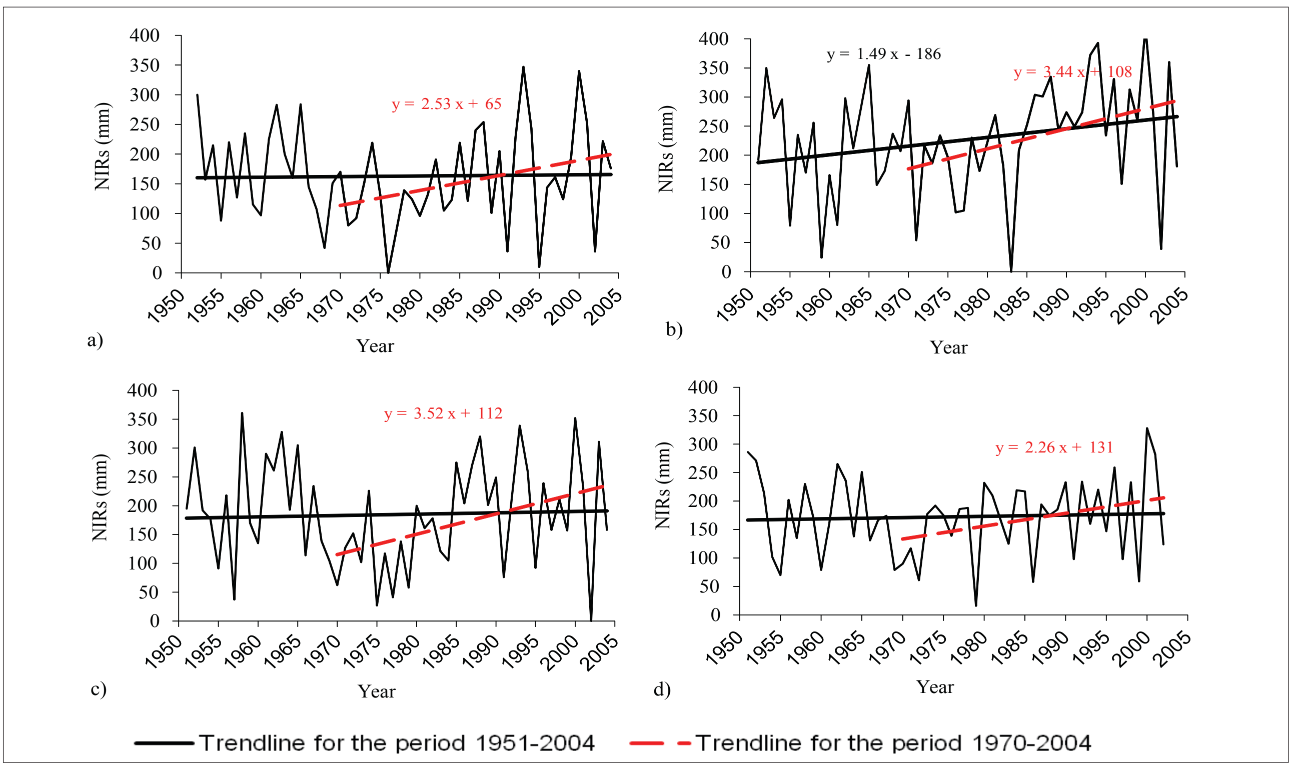

Fig. 12. Trendline of net irrigation requirements NIRs, mm, of maize at: a) Sofia; b) Plovdiv; c) Pleven; d) Silistra; late hybrids (H708, 2L-602 and BC622), soils of medium water holding capacity (TAW=136-157 mm·m^{-1}), 1951-2004 vs. 1970-2004

that two additional irrigation events should be required in the dry years of the present climate.

Using the SPI-2 as water stress indicator for rainfed maize and water management

A variety of indices exist to support operational drought management (Pereira et al., 2009; Mishra and Singh, 2010; NDMC, 2013). The Standard Precipitation Index, SPI (McKee et al., 1993; 1995), the mostly used in South East Europe (Gregoric, 2012), is a standardized index which computation is based on the long-term precipitation record cumulated over a selected time scale, shorter when meteorological or agricultural droughts are considered, longer when the analysis aims at water supply management. That long-term precipitation record is fitted often to the gamma distribution that is transformed through an equal-probability transformation into a normal distribution. Positive SPI values indicate greater than median precipitation, and negative values indicate less than median precipitation.

It is important to relate RYD with the SPI-$2_{Jul\text{-}Aug}$ because the SPI is standardized and therefore is well comparable among locations and from a year to another (Guttman, 1998; Lana et al., 2001; Bordi et al., 2009). In addition, it contains a probabilistic interpretation. Thus, when using SPI values, one knows when precipitation at a given location is near normal, or is anomaly in excess or deficit, and may easily compare among locations with different climatic characteristics. SPI-$2_{Jul\text{-}Aug}$ provides therefore a quick information for management, namely when mapped at country level.

SPI-$2_{Jul\text{-}Aug}$ were related to RYD for all eight climate regions under study. Examples of the linear relationships obtained are shown in Figures 13a and 13b. Statistical results are given in Table 5 and they include the determination coefficient (R^2), the re-

Table 5
Linear regression parameters relative to relationships between RYD (%) with the SPI-2July-Aug across the considered soil groups and climate regions, Bulgaria, 1951-2004

Region		Soil Groups according to TAW		
		Small: 116 mm m^{-1}	Medium: 136-157 mm m^{-1}	Large: 173-180 mm m^{-1}
		RYD %	RYD %	RYD %
Sandanski	Intercept *a*	79.6	74.1	62.1
	Slope coefficient *b*	-15	-15.7	-16.1
	R^2 (%)	75	77	78
Stara Zagora	Intercept *a*	67	61.81	51.3
	Slope coefficient *b*	-19.9	-20.5	-20.5
	R^2 (%)	80	82	83
Plovdiv	Intercept *a*	65.2	59.4	47.2
	Slope coefficient *b*	-24.8	-24.7	-23.6
	R^2 (%)	92	92	91
Lom	Intercept *a*	57.7	51.3	38.5
	Slope coefficient *b*	-23.8	-23.6	-22.1
	R^2 (%)	86	86	86
Sofia	Intercept *a*	48.4	42.6	31.2
	Slope coefficient *b*	-21	-20.5	-18.8
	R^2 (%)	76	75	73
Silistra	Intercept *a*	56.1	49.1	35.9
	Slope coefficient *b*	-20.5	-20.3	-19.3
	R^2 (%)	86	86	86
Pleven	Intercept *a*	53.5	47.6	35.7
	Slope coefficient *b*	-23.3	-23	-21.6
	R^2 (%)	82	81	79
Varna	Intercept *a*	63.6	56.9	43
	Slope coefficient *b*	-18.1	-17.6	-16.5
	R^2 (%)	82	81	80

gression coefficient (b) and the intercept (a) when relationships are computed for low, medium and high TAW soils.

The determination coefficients are generally high, which means that a large fraction of the RYD variation is explained by the SPI-$2_{Jul\text{-}Aug}$, i.e., by the dryness conditions during the maize peak demand period. Changes of R^2 for different soils are negligible. These results confirm the preceding analysis and the possibility of using SPI-$2_{Jul\text{-}Aug}$ as an indicator of water deficit not depending on the soil type. The regression coefficients may be assumed as indicators of the linear yield decrease of RYD when SPI-$2_{Jul\text{-}Aug}$ decreases from its maximum (wet conditions) to low (and negative) values referring to dryness (Figure 13). Results show that their values change little among the regions and, for each location, among soil groups. Differently, the intercept (value of RYD when SPI-$2_{Jul\text{-}Aug}$ = 0) depends upon the soil group: the intercept decreases from low to high TAW since dryness has larger influence on RYD when TAW is small.

When monitoring precipitation, the adoption of SPI-$2_{July\text{-}Aug}$ may be useful to manage the risk of economic losses with rainfed maize by advising farmers to adopt supplemental irrigation if water is available at farm (Figures 13c and 13d). The related farm advising may be regionally oriented and take into consideration the dominant soil type (as for the RYD and NIR further

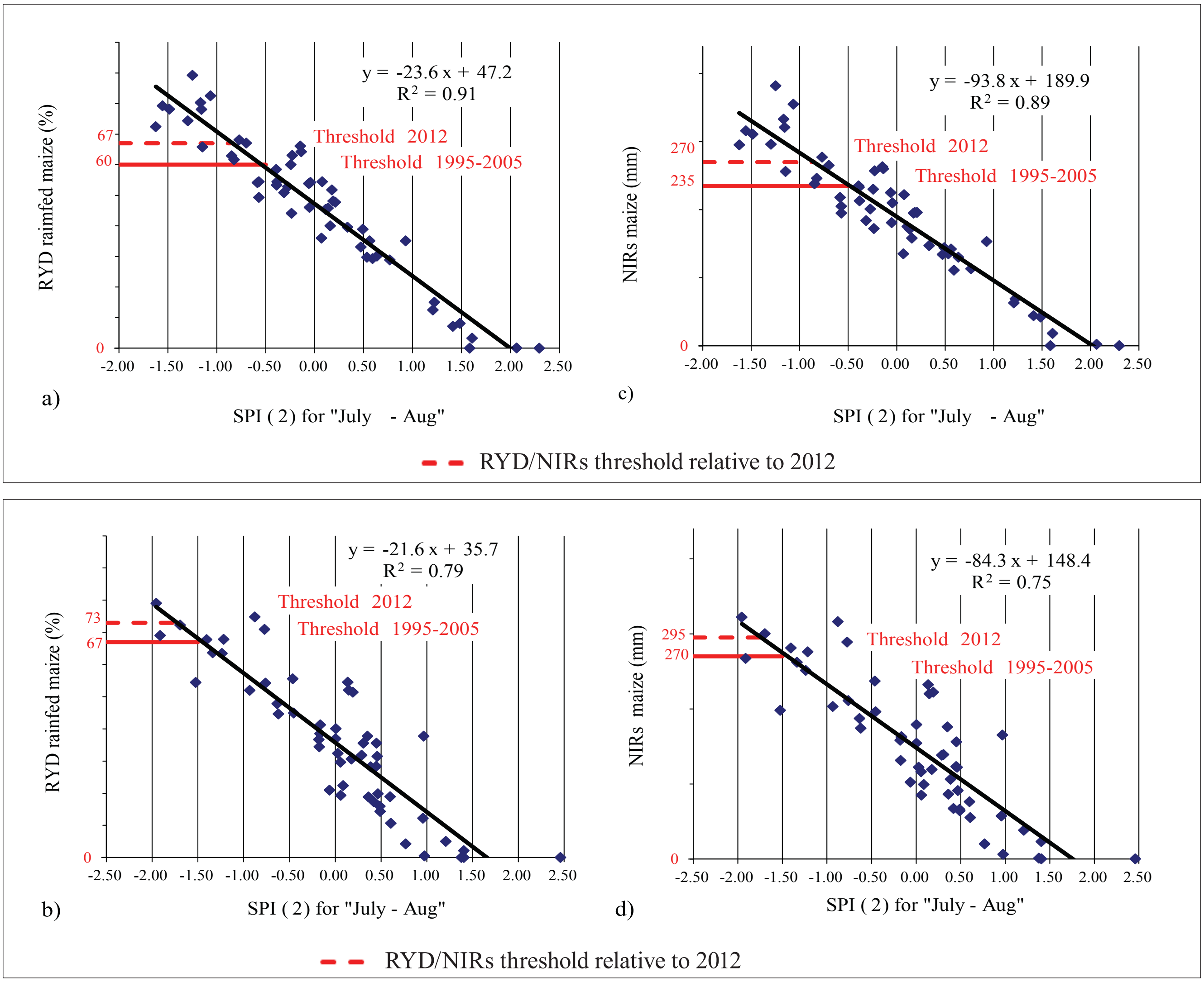

Fig. 13. Relationships between seasonal SPI2 $_{\text{“July-Aug”}}$ and relative yield decrease of rainfed maize RYD or Net irrigation requirements NIR for: a) and c) Plovdiv and b) and d) Pleven; soils of large TAW (180 mm m^{-1}), late maize hybrids

mapping in Figures 16 and 17). It needs to reflect in addition the actual economic farming conditions using the relationships in Fig.9b, as it is in the case of risen grain price (from 200 to 400 BGN t^{-1}) and production expenses (from 800 to 1200 BGN ha^{-1}) during the extremely dry 2012 (Figures 14a and 14b).

The SPI-$2_{July-Aug}$ threshold, when computed for the values of RYD that do not produce economic losses, may be used as indicators of dryness that affects yields. These values are represented in Figure 14 for all locations and soil groups including, when the change in economic condition was considered (Figure 14b). It can be observed that for Pleven and soils with high TAW negative economic impacts occur only in severely/extremely dry peak demand periods when SPI-$2_{July-Aug}$ < -1.5 while for Sandanski such impacts occur for SPI-$2_{July-Aug}$ < +0.10. This also indicates that the region of Sandanski is extremely vulnerable to water deficits in rainfed maize systems or, in other words, that rainfed maize is not viable there. This is due to the predominant climate, of Mediterranean type, where rainfall in summer is low, much less than in all other regions of Bulgaria.

Results show that in the Thrace Plain (Plovdiv and Stara Zagora), for soils with low or medium TAW, rainfed maize

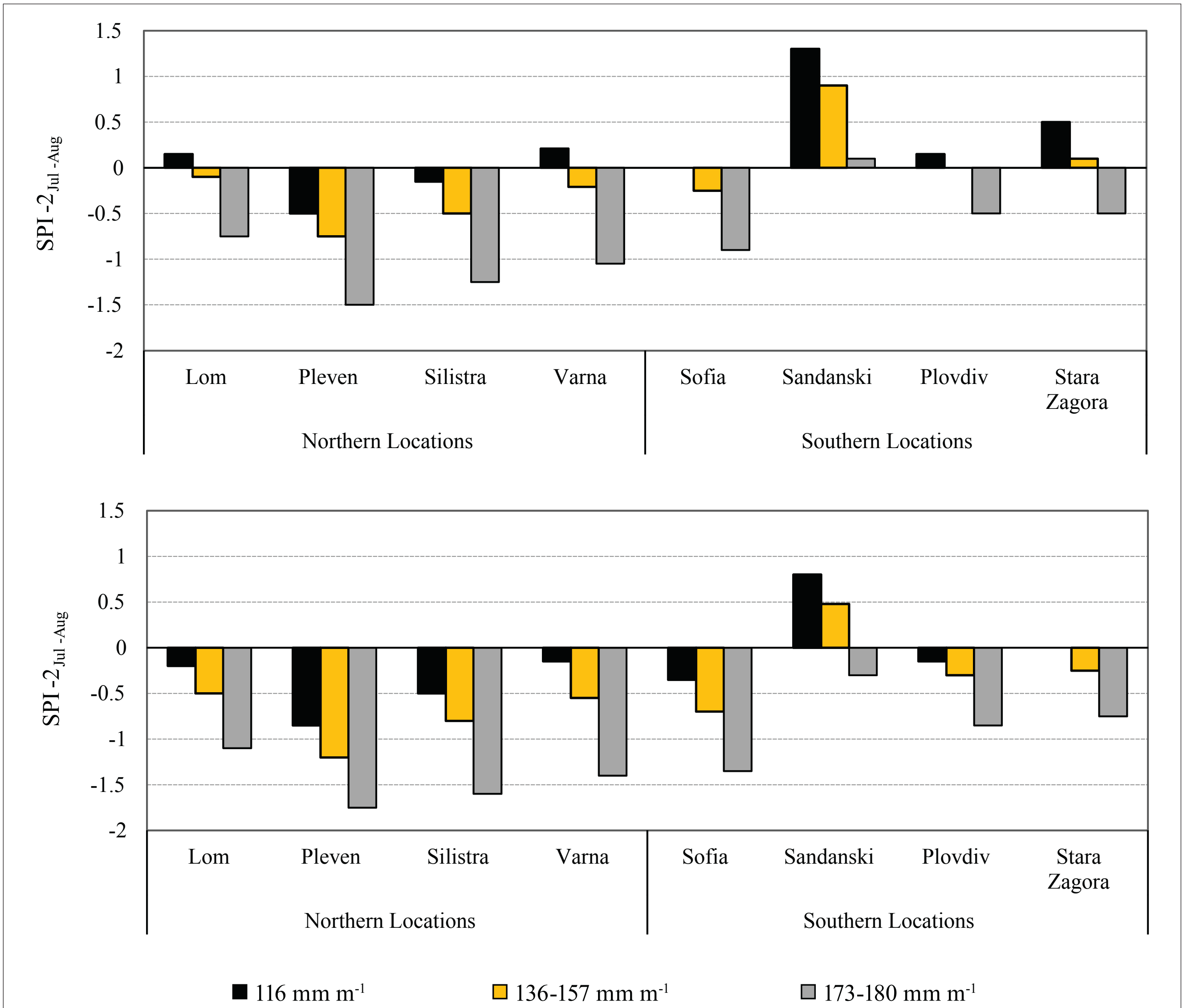

Fig. 14. Threshold values of SPI2 $_{\text{“July-Aug”}}$ indicative of economic risk for rainfed maize in various regions and soil groups having small (116 mm m^{-1}), medium (136-157 mm m^{-1}) and large (173-180 mm m^{-1}) TAW relative to the economical conditions of: a) 1990-2005 and b) the very dry 2012

is vulnerable to dryness even when SPI-$2_{July-Aug}$ are not negative, which indicates a high vulnerability to water stress in that area (Figure 14a). However, that vulnerability is lower for soils with high TAW when SPI-$2_{July-Aug}$ thresholds are not lower than -0.50. In North Bulgaria conditions are more favourable but the risk of economic losses is high for soils with low TAW mainly along the Black Sea coast (Varna) and in the region of Lom.

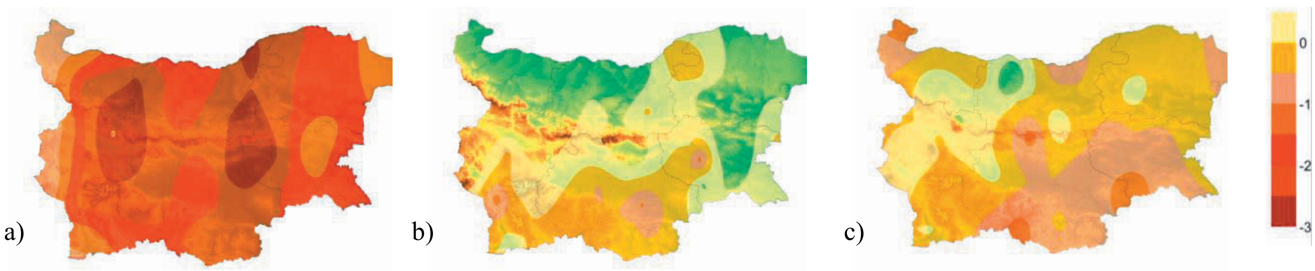

Fig. 15. Spatial distribution of seasonal SPI2 "July-Aug" relative to the year of: a) extreme (2000), b) average (1970) and c) moderate (1981) irrigation demand, Bulgaria

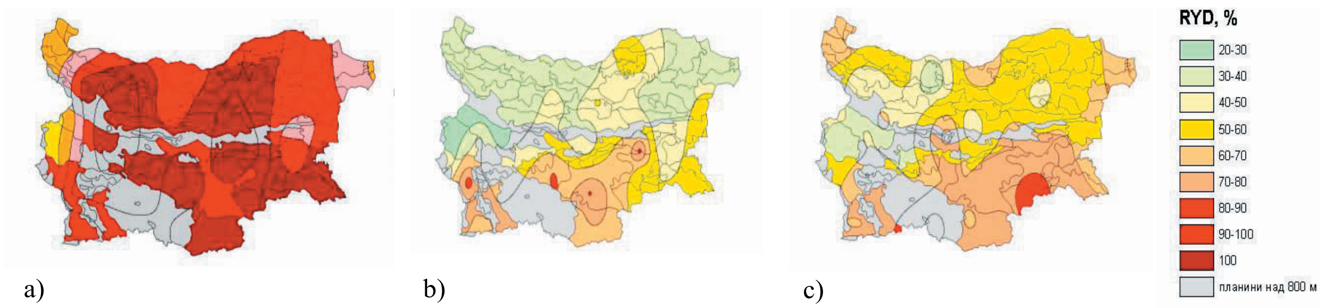

Fig. 16. Spatial distribution of relative yield decrease (RYD, %) for rainfed maize relative to the year of: a) extreme (2000), b) average (1970) and c) moderate (1981) irrigation demand, Bulgaria

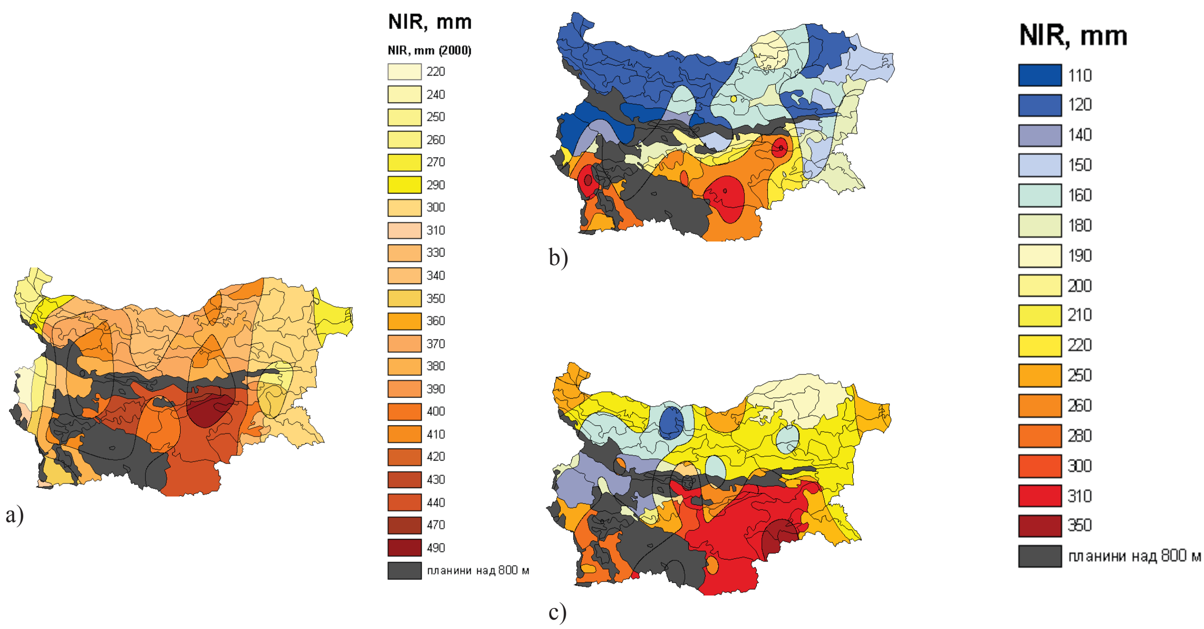

Fig. 17. Spatial distribution of net irrigation requirements (NIR, mm) for maize relative to the year of: a) extreme (2000), b) medium (1970) and c) moderate (1981) irrigation demand, Bulgaria

Mapping RYD of rainfed maize and irrigation requirements to cope with drought

The results of the study are used for mapping the hazards of drought and identification of drought prone territories in Bulgaria. Maps of the SPI2 $_{\text{“July-Aug”,}}$ illustrate the dryness conditions during the maize Peak demands period relative to the very dry (2000), the average demand (1970) and the moderately dry (1981) year of presented in Figures 15a, 15b and 15c.

The latter maps, The map of Soil Geographical Regions (Koinov et al., 1998) and the derived relationships between simulated *RYD* (%) and the indicator of water deficit for rainfed maize SPI2 $_{\text{“July-Aug”}}$ (Table 5) are used to predict the distribution of hazardous yield losses for maize in Bulgaria in the same years (Figures 16a, 16b and 16c).

The elaborated maps correspond to soils of medium *TAW* (136-157 mm m^{-1}) that are widespread in a different degree over the main geographical regions of Bulgaria. Thus they express the hazard of drought and further the irrigation management to support farmers (Figures 17a, 17b and 17c).

Conclusion

This study, relative to rainfed maize crop, was applied to eight Bulgarian climate regions and three soil groups, and the period 1951-2004.

Relative to climate change, significant negative trends for precipitation during Peak Demand Season “June-Aug” were identified in The Thrace region, which are combined with the respective positive trends for ETo $_{\text{June-Aug}}$.

An analysis relative to the present climate period 1970-2004 shows a trend for aggravation of drought not only in The Thrace but also in the northern locations and Sofia field, thus confirming that agricultural lands in Bulgaria experience an increased vulnerability to water stress.

Rainfed maize is associated with great yield variability (29% < Cv < 72%).

It was possible to define probability curves relative to the RY decreases and to the required irrigation NIR to avoid these yield deficits. Therefore, based on economical considerations, thresholds defining the risk associated with water deficits could be computed.

Linear relationships were found relating RYD with the SPI-$2_{\text{July–Aug}}$. The determination coefficients were generally high, thus indicating that a large fraction of the RYD variation is explained by the SPI-$2_{\text{July–Aug}}$, i.e. by the dryness conditions during the maize peak demand period. These results allow considering the SPI-$2_{\text{July–Aug}}$ as an indicator of water deficit for rainfed maize, which is not depending of the soil type. The regression coefficients may be assumed as indicators of the linear yield decrease of RYD when SPI-$2_{\text{July–Aug}}$ also decreases from maximum values (wet conditions) to low negative ones, again not depending upon the soil type. Differently, the intercept (value of RYD when SPI-$2_{\text{July–Aug}}$ = 0) reflects the soil group and decreases from low to high soil TAW.

Moreover, it was possible to define the SPI thresholds for each region and soil TAW relative to the peak period of July-August, SPI-$2_{\text{July-Aug}}$ when decreased yields lead to economic losses. Results show that vulnerability to water stress decrease when soils have a higher soil water holding capacity, and that vulnerability is higher in southern regions than in northern ones. SPI-$2_{\text{July-Aug}}$ value may support advising farmers about the risk of economic losses and to adopt then supplemental irrigation.

The derived reliable relationships and specific thresholds of seasonal SPI2 $_{\text{“July-Aug”}}$, under which soil moisture deficit leads to severe impact of drought on rainfed maize yield for the main climate regions and soil groups in Bulgaria, are representative of a wider area of Moderate Continental, Transitional Continental, Transitional Mediterranean and Black Sea climate in SEE. They are used for elaboration of RY decreases and irrigation requirements’ maps, as well as for identification of drought prone territories and coping with drought at regional and national level.

Further studies are desirable in terms of analyzing the constraints of irrigation as an adaptation measure to cope with droughts and climate change.

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