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OPTIMUM REGIONAL IRRIGATION REQUIREMENTS UNDER CHANGING CLIMATE IN BULGARIA

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Abstract

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Net irrigation requirements (NIR, mm) that fully satisfy crop development and yield formation are basic in irrigation systems' design and management. Bulgarian practice usually adopts the irrigation scheduling developed by Zahariev et al. (1986) that provide information on 31 crops and 97 irrigation regions (IR). Years, having probability of occurrence of an irrigation depth P_I=10, P_I=25 and P_I=50%, were considered. To cope with climate uncertainties and drought aggravation, simulations were performed for past (1950-1980) and present (1951-2004) weather conditions of unified Agro-Climatic AC regions. In former studies the irrigation scheduling simulation WinISAREG model was calibrated for maize using data from long-term experiments carried out in fields of diverse soil, climate and management conditions. Optimal AC regions were defined on the grounds of average reference evapotranspiration totals for July-August relative to the period 1951-2004 $ET_{oJul\text{-}Aug}$. Thus, $ET_{oJul\text{-}Aug}$ served as an indicator of regional NIR and IR unification into AC regions. The impacts of soil properties were characterised by total available soil water TAW, being "small" if TAW=116, "average" if 136<TAW<157 and "large" when 173<TAW<180 mm m^{-1}. NIR were computed by model application to soils of small and large TAW in each AC region and 1951-2004 period. Results indicate that when EToJul-Aug increases from 260 to 330 mm, NIR in "average" demand year (P_I=50%) increase from 160 to 310 mm for soils of "small" TAW. Relative to 1951-1980, unified conventional irrigation demands were compared to those simulated. Results showed that the former were mostly in the range of those derived by model simulations. It was concluded that the model took better into account the impact of climate change and different TAW. Maps illustrate findings of the study over country territory in "an average", "a moderately dry" and "a very dry" season.

Key words: Regional irrigation requirements, ETo, WinISAREG model, Climate Change

Introduction

Net irrigation requirement that fully satisfies crop water requirements for development and yield formation is basic in designs and management of irrigation systems. Completely different is the problem of irrigation demand when a maximum economical return is aimed at. Conventional Bulgarian irrigation practice usually adopts the irrigation scheduling and demands developed by Zahariev et al. (1986) that are based on experimental data relative to the period 1950-1980 and

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application of Delibaltov's equition of crop evapotranspiration (1959):

$$ET=Z.\ \Sigma\ t^{o} \qquad (1)$$

where Z – a coefficient that takes into account crop variety and development stage; $\Sigma\ t^{0}$ – a total average daily air temperature over a decade.

The book of Zahariev et al. consists predominantly of tables that provide information on the timing of a conventional application depth of 60 mm and the respective seasonal irrigation demand (ID) relative to 31 crops and 97 irrigation regions (IR). Three particular years having probability of occurrence of an ID P_I=10%, P_I=25% and P_I=50% are considered respectively. The huge volume of the book however hampers its practical application that makes advisable to reduce the number of regions.

Climate change and drought aggravation detected during the last 35 years have created uncertainties for irrigation management in this country (Alexandrov, 2011; Popova et al., 2014; Moteva et al., 2015). Undoubtedly, they have influenced crop evapotranspiration, yield decrease due to water stress and corresponding net irrigation requirements to overcome these losses (Popova and Pereira, 2008; Popova, Ivanova and Doneva, 2014; Popova and Ivanova 2015; 2016a; 2016b). In 1998 FAO published a new methodology on reference evapotranspiration calculation using the equation of Penman-Monteith (Allen et al, 1998). Numerous climate parameters, as maximum and minimum air temperature and others are involved in the suggested relationship. Independent studies, carried out in different parts of the world, have shown that the validated ETo-PM-FAO56 equation takes better into account the impact of variable microclimatic factors on reference and actual crop evapotranspiration (Liu et al., 1998; Liu and Pereira, 2001; Popova, Kercheva, Pereira, 2006; Popova, 2008; Pereira et al., 2015). The objective of the present study is to provide a practically oriented methodology on regional irrigation requirements optimization under the conditions of climate uncertainties in Bulgaria by applying the previously validated water balance and irrigation scheduling WINISAREG simulation model to maize crop (Pereira et al., 2003; Popova, Eneva, Pereira, 2006; Ivanova and Popova, 2011; Popova and Pereira 2011). The unification of irrigation regions is based on the average reference evapotranspiration totals for July and August $ET_{0\ July-Aug}$.

Developed methodology

Variability of soil characteristics is really substantial in this country (Boneva, 2012). Regarding irrigation scheduling and net irrigation requirement NIR, mm, however the impact of soil has been taken directly into account by Total Available Soil Water TAW mm m^{-1}. The latter is computed as a difference between soil water storage at Field Capacity (FC) and Wilting Point (WP). In Popova (ed.) 2012 the impact of soil characteristics on net irrigation requirement is taken into account by the difference mentioned above. The characteristic of "small" available soil water is related to the group of soil varieties having TAW=116 mm m^{-1}. The soils of "medium" water holding capacity are those of TAW within the range 135-157mm m^{-1}, while those of "large" TAW have a 173-180mm m^{-1} difference between FC and WP.

Climate conditions are the main factor when computing crop water requirement for irrigation. In the present study it is characterized by average reference evapotranspiration ETo estimated by the Penman-Monteith equation according to the methodology of FAO 56 (Allen et al., 1998). In 2008 Moteva, Kazandjiev, Georgieva determined ETo using required climate data monitored on a daily basis in 30 representative Agro-Meteorological (MS) stations of the country over the period 1971-2000. Average cumulative totals of $ET_{0\ July-Aug}$ were computed for three typical periods of crop development: March-October, April–June and July-August. The example developed below deals with grain maize. The main part of irrigation for this and other summer crops usually takes part in "July-August". Thus, it is accepted that the impact of climate on soil water balance and crop development under irrigated maize could be characterized precisely by using the average total of reference evapotranspiration over the period "July-August". For example average total $ET_{0\ July-Aug}$ is 220 mm in the station of Dragoman, while it is 320mm in the station of Sandanski, i. e. the difference is about 100 mm. Thus, it makes sense to divide the plain country territory into five Agro-Climatic (AC) regions. The average values of $ET_{0\ July-Aug}$ relative to each of the unified regions over the period 1971-2000 are respectively: 230, 250, 270, 290, и 310 mm (Table 1).

The average totals of $ET_{o\ July-Aug}$ presented within parentheses in the same table 1, namely 260, 275, 285, 310 и 330, refer to the longer 1951-2004 period. They were delivered during our previous studies (Popova (ed.), 2012) using climate data on maximum and minimum air temperature observed in the Agro-Meteorological Stations (MS) of Sofia, Silistra, Lom/Varna, Pleven/Plovdiv and Sandanski respectively by National Institute of Meteorology and Hydrology. The ET_o calculation procedures are those recommended by FAO56, applied after respective validation as described in Popova, Kercheva, Pereira, 2006; Popova, 2008 and Popova (ed.)

2012. Thus, each of the estimated $ET_{o\ July\text{-}Aug}$ value would differ by less than 10 mm that is 4.5% from the average regional values given in Table 1. Presuming the requirements of irrigation practice, such deviations are completely acceptable.

Undoubtedly, when considering another crop like wheat, vegetables and others, the period of substantial climate impact on NIR should be completely different. It should be point out as well that when using experimental data as a basis of validation for each evapotranspiration calculation method, errors are unavoidable and not less than 10%.

Respective NIR were computed by application of the validated water balance and irrigation scheduling WinISAREG model to soil groups and climate stations representing the main agro-climatic regions of this country (Popova (Ed.) 2012; Popova et al., 2014; 2015). In table 1, in addition to average reference evapotranspiration sum $ET_{o\ July\text{-}Aug}$, net irrigation requirement NIR relative to different levels of probability P_I [%] of a NIR occurrence 10, 25, 50, 75 and 90% is presented as well. The latter takes into account the possible range of NIR variability for maize crop over more that 90% of the years within the period 1951-2004. In each cell of the table, the upper number refers to the soil group of "small" TAW (116 mm m^{-1}) while the lower number is valid for the group of "large" TAW (173-180 mm m^{-1}). NIR relative to the soil group of "average" TAW is about 20 mm less than that simulated for soils of "small" water holding capacity TAW=116 mm m^{-1}. Meteorological station (MS) that provide the required climate data to each Agro-Climatic (AC) region are listed in the second column of table 1 (Moteva et al., 2008; Popova (ed.) 2012).

Referring to III and IV AC Regions of average total $ET_{0\ July-Aug}$ 285 and 310 mm respectively (Table 1), it is observed that NIR values relative to Varna and Pleven are separated from the others in the group since they differ from them by up to 50 mm from them.

When average total $ET_{oJul\text{-}Aug}$ increases from 260 to 330 mm, NIR in "the average" demand year (P_I=50%) increase from 160 to 310 mm when soils of "small" TAW are considered. Such range of deviation is substantial and reflects the impact of climate uncertainty on maize irrigation in this country. When net irrigation requirements NIR relative to soils of large water holding capacity are less than 40 mm in the very wet years (P_I >90%), it is admissible not to irrigate.

Result and Discussions

1. Estimation of net irrigation requirement by using WINISAREG model and experimental data.

Net irrigation requirement NIR, mm, for maize crop computed by using the validated WinISAREG model (Popova and Pereira, 2011) is compared with that estimated on the grounds of a 9-year irrigation experiment carried out in Tsalapitsa field, Plovdiv region (Varlev, Kolev, Kirkova, 1994). The probability curve of occurrence of a NIR shown in Fig.1 is built upon simulations over a 54-year period (1951-2004).

In that case monthly precipitation data observed at Tsalapitsa field (1970-2004) were extended to a longer period (1951-2004) by using a previously derived statistically significant correlation between available data for Plovdiv and Tsalapitsa (R^2=0.74) with a regression coefficient b=0.89 (Popova et al., 2011). Correlations for extending average monthly maximum T_{max} and minimum air temperature T_{min} were derived in a similar way, producing quite significant correlation (R^2=0.96-0.997) with a regression coefficient b=0.926-0.974.

In the same Fig. 1 respective net irrigation requirements for maximum yield during each experimental season over 1983-1991 are plotted in open symbols (o) as well. It is observed that, except for the NIR in two of the wet seasons in 1989 (P_I=70%) and 1983 (P_I=85%), model simulation results practically coincide with experimentally based ones (Fig. 1). Thus, computed NIR relative to the period mentioned above, are acceptably precise and could be used in the irrigation practice. Observed deviation in the two wet years having probability P_I=70% and P_I=85% (about 40mm) is logic since the 54-year period is much more representative that that of a 9 - year field experiment (Fig. 1). The results also indicate that extreme values of NIR are registered only during the longer 54-year period and do not occur during the period of field experiments.

Results in Fig. 2 refer to the empirical probability curves of occurrence of a net irrigation requirement NIR mm under fully irrigated maize in Plovdiv, computed by WinISAREG simulation model when the impact of three soil groups of different TAW is considered. The highest curve refers to a soil of "small" TAW of 116 mm m^{-1}, as the soil in Tsalapitsa is. The results are based again upon the 1951-2004 period (54-year).

The figure also shows that maize cultivation in soil of "large" TAW (180 mm m^{-1}) leads to much less NIR than that relative to soil of "small" TAW.

2. Comparing irrigation requirements by "Zahariev et al." and those computed by using WinISAREG model

It is well deserved to find out the difference between the experimentally based seasonal irrigation depths derived by Zahariev et al.(1986) and those got after unification of relevant model simulations results (Popova (Ed.) 2012) within

Table 1. Net Irrigation Requirements of maize NIR [mm] depending on probability P_I of occurrence of a NIR in the Unified Agro-Climatic (AC) regions of Bulgaria, 1951-2004.

Average Reference Evapotranspiration $ET_{0\ July-Aug}$ [mm] for the periods 1971-2000 and (1951-2004)	Agro Meteorological station (MS)	Probability P_I [%] of occurrence of a NIR				
		10	25	50	75	90
230 (**260**) **AC region I**	**Sofia**, Dragoman	280/230	230/180	**160**/110	120/70	80/30
250 (**275**) **AC region II**	Knezha, Pavlikeni, Targovishte, V.Tarnovo, G. Delchev, Dobrich, **Silistra**	300/240	240/190	180/130	140/90	90/40
270 (**285**) **AC region III**	Vidin, **Lom**, Obraztsov chiflik, Kyustendil, Rila, Kazanlak, Ivanova, Karnobat	320/260	260/210	200/150	160/100	90/40
	Varna	300/240	240/190	210/160	140/130	130/50
290 (**310**) **AC region IV**	**Pleven**	330/270	280/210	210/140	130/80	80/20
	Yambol, Sadovo, Plovdiv, Elhovo, Chirpan, Sliven, Burgas	370/310	310/260	250/200	190/135	100/40
310 (**330**) **AC region V**	Haskovo, Svilengrad, Petrich, **Sandanski**	380/310	360/300	**310**/270	280/210	240/180

five Agro-Climatic regions (AC). For that purpose Table 2 and Maps of Net Irrigation Requirement relative to different climatic years are composed (Figs. 3a 3b 3c) that also mark the location of MS, IR and unified AC regions.

In contrast to the results object of our study in Table 1 that are based upon model simulations over the 1951-2004 period, table 2 is related to the shorter 1951-1980 period that represents the "past" weather conditions. Table 2 consists of data on net irrigation depth estimated by Zahariev et al. (1986) in 30 Irrigation Regions (IR) during the years of probability P_I of a NIR occurrence 10, 25, 50%. Table 2 presents also the simulated net irrigation requirement when the impact of soils of "small" (116) and "large" (173-180) total available water TAW mm m^{-1} is taken into account.

It is observed that in AC region IV of average total $ET_{oJul-Aug}$=292 mm irrigation depth of "Zahariev" is 240 mm at IR Plovdiv, Elhovo, Sliven and Yambol in "average" irrigation demand year (P_I=50%), while simulated NIR by WinISAREG model application to soils of diverse water holding capacity is within the range 230-170 mm. Regarding the dry year (P_I=10%), experimentally based irrigation depth of "Zahariev" is 300 mm at all compared IR, while in model simulation it is within the range 320-260 mm.

Similar results are found in the remaining AC regions of average total $ET_{oJul-Aug}$ 258, 272, 281, 286 and 315-326 mm (Table 2). Diversity of irrigation depth in some of the examined

AC regions, for instance those around Varna, is

due to the remoteness of IR from the MS (o, Fig.3) or spatial variability of precipitation. In most of the cases however the irrigation depth by "Zahariev-1986", after IR unification into five AC regions, is within the range of NIR found by the application of validated WinISAREG model.

Considering the AC regions I and II of $258<ET_{oJul\text{-}Aug}<272$ mm, the seasonal irrigation depths of 300, 240 and 180 mm by "Zahariev-1986" are valid in eight of ten IR and quite close to simulated NIR at Sofia and Silistra (Table 2, Fig.3).

Referring to AC region III of $272<ET_{oJul\text{-}Aug}<281$ mm, irrigation depth combinations rise to five in totally eight irrigation regions IR while NIR increases from 240, 240 and 180 mm at IR86Kazanlak to 300, 300 and 240 mm at IR1Vidin and IR47 Varna-Goren chiflik. The maps also show that IR46-48Markovo, Provadia and Goren chiflik (o, Fig. 3) are far off the coastal zone by 50-70 km. As a result the irrigation depth by "Zahariev-1986" surpasses the simulated one when using Northern-Black Sea climate data observed in the Varna MS (Table 2). Only in the dry year ($P_I=10$) and in soils of "large" TAW the "Zahariev" irrigation depth surpasses the simulated one by 110 mm. The difference however becomes smaller (20-50 mm) in the case of soils of "small" TAW.

Regarding AC region IV of $286<ET_{oJul\text{-}Aug}<292$ mm, the combinations of irrigation depth are four at the IR17-22Pleven (Table 2, Fig.3). Table 2 shows that "Zahariev" seasonal irrigation depths of 300, 300 and 240 mm at probability level $P_I=10$, $P_I=25$ and $P_I=50\%$ occur in half of the IR of AC region IV.

Irrigation depth relative to AC region V of $ET_{oJul\text{-}Aug}=326$ mm increases by 60 mm during the dry years when compared with those relative to AC region IV. Irrigation depth in the average demand year however increases only in the southernmost IR66 Petrich, 81 Svilengrad and 65 Sandanski (Table 2)

Finally, it is concluded that net irrigation requirement NIR simulated by the validated WinISAREG model varies in a larger range than that published by Zahariev et al. (1986). Thus, the model takes better into account the impact of variable water holding capacity of the soil and climate uncertainties in this country.

3. Mapping and analyses of irrigation requirements

It is of interest to follow the dynamics of "wet" and "dry" areas of drought intensity on maps that represent distribution of Net Irrigation Requirement in the scale of the country in "an average"1970, "a moderately dry"1981 and "the extremely dry"2000 over the period 1951-2004 (Figs. 3a 3b 3c). Symbols and names of MS, numbers of IR by "Zahariev" unified in Agro-Climatic AC regions according to $ET_{oJul\text{-}Aug}$ are plotted as well (Figs. 3a 3b 3c).

Spatial distribution of NIR in Fig. 3a shows that 1970 is really "average" in terms of irrigation requirements at AC regions II, IV and V in South Bulgaria but "wet" at AC regions I (Sofia), II, III and IV (Central North and North-West Bulgaria). The same characteristics could be indicated by the probability curves of occurrence of a NIR at different locations showing that PI is within the range 45-60% at Tsalapitsa, Stara Zagora, Sandanski and Sofia when $P_I=25$ at Plovdiv in 1970 (Figs. 1 and 2; Popova (Ed.) 2012). It is observed also that in 1970 the dominant code in South Bulgaria is "brown" of NIR=250 mm in the Thrace and "orange" of NIR=300 mm, indicating a higher drought intensity around Haskovo, Yambol and Rila. "Yellow" code of NIR=220/230 mm spreads over IR of Elhovo and Stara Zagora, while a "green" one of NIR=180 mm pervades along the Black Sea coastal area.

In 1970 the "blue" code of 110<NIR<120 mm prevails in IR52 Sofia and IR53 Elin Pelin (AC region I), over Central and North-West Bulgaria (AC regions II, III, IV) and also around IR43Silistra and IR37 Targovishte. Logically, such low irrigation requirement has a high level of probability of occurrence in IR17-22 Pleven, IR5 Lom (P_I=90-95%) and IR43 Silistra ($P_I=70\%$) (Popova (Ed.), 2012). Net irrigation requirement increase to 150-180 mm at probability level $P_I=85\%$ in IR46-48 around Varna.

During the "moderately dry" 1981 (Fig. 3b) the whole territory of AC regions IV (Plovdiv, Sliven, Yambol, Elhovo) and V (Stara Zagora, Haskovo and Svilengrad) in South Bulgaria is caught by a high intensive drought of "orange" code for NIR=350 mm. On the contrary, the "blue" wet zone of 110<NIR <120 mm in North Bulgaria shrinks substantially to IR17, 18, 19 and 20 around Pleven and IR37 Targovishte. The IR of Knezha, Belene, Levski and Pavlikeni in AC regions II and IV pass over to the zone of a higher NIR=190 mm. A typical feature of 1981 is that dryness sweeps the zones around Vidin, between Ivanovo and Belene (NIR=250 mm) and near Shabla (NIR=210 mm) in North Bulgaria.

During the "extremely dry"2000 the "blue" zone of "small" NIR disappears, while drought intensity increases all over the country (Fig. 3c). As a result, Net Irrigation Requirement reaches the record 490 mm in AC regions IV (Sliven) and V (Stara Zagora), 440 mm in Kazanlak, Yambol and Svilengrad, 410 mm in Plovdiv, Elhovo and Rila and 390-340 mm in AC region I (Sofia). The "yellow" code of NIR=240-290 mm dominates the extreme East and West regions of North Bulgaria. "Brown" zone of NIR=410 mm appears in IR15Knezha, 28Veliko Tarnovo, 30Gorna Oryahovitza and Obraztsov chiflik, while the "green" code relative to IR18-22Pleven, 67Targovishte, 43Silistra and 46-48 Varna points to NIR=310-330 mm.

Table 2. Comparing irrigation demands by "Zahariev – 1986" and WINISAREG model, 1951-1980

Average seasonal $ET_{oJul\text{-}Aug}$ (mm), 1951-1980	Source	Agro-Meteorological station / [MS]and Irrigation region (IR)	Net irrigation requirements NIR, mm, with probability P_I [%]		
			P_I =10%	P_I =25%	P_I =50%
258	Mathematical model	Sofia	300/250	230/180	160/110
AC region I (🟡)	„Zahariev "	Elin Pelin IR 53	240	180	180
		Sofia IR **52**	**300**	**240**	**180**
272	Mathematical model	Silistra	285/230	235/175	190/140
AC region II (🟢)	„Zahariev "	Pavlikeni IR **29**, Targovishte IR **37**, Knezha IR **15**,V. Tarnovo(Karsisen IR **28** and G. Oryahovitsa IR **30**), G. Delchev IR **67**;	**300**	**240**	**180**
		Silistra IR 43	300	300	240
281	Mathematical model	Lom	290/230	240/190	190/140
AC region III (○)		Varna	250/**190**	220/170	205/150
	„Zahariev "	**Kazanlak IR 86**;	**240**	**240**	**180**
		Kyustendil IR60,Rila IR 62, Varna–Markovo IR 46;	300	240	180
		Varna–Provadia IR 48,	300	240	240
		Vidin IR 1, Varna-Goren Chiflik IR 47	**300**	**300**	**240**
272		Lom IR 5	360	300	240
286	Mathematical model	Pleven	325/270	245/190	190/130
AC region IV (🔴)	„Zahariev "	IR 17-22:Sadovec (17);	300	240	180
		Levski (22);	300	300	180
		Dolna Mitropolia (18), Novachene (20);	**300**	**300**	**240**
		Gulyantsi (19), Belene (21)	360	300	240
	Mathematical model	Plovdiv	320/260	280/220	230/170
292	„Zahariev "	Sliven IR 89, Yambol IR91;	300	240	240
		Plovdiv IR 72, Elhovo IR92	**300**	**300**	**240**
315	Mathematical model	Stara Zagora (IR 85)	320/280	300/250	250/200
	„Zahariev "	Stara Zagora	300	240	180
326	Mathematical model	Sandanski IR 65	380/320	350/300	300/240
AC region V (🔵)	„Zahariev"	Haskovo IR 83;	**360**	300	240
		Petrich IR **66**, Svilengrad IR **81**;	**360**	300	**300**
		Sandanski IR **65**	**360**	**360**	**300**

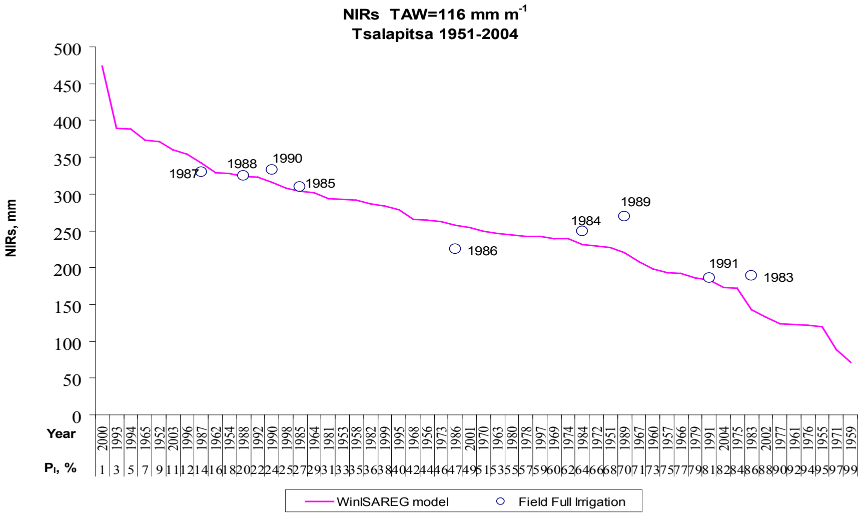


Fig. 1. Probability curve of occurrence of a Net irrigation requirement (NIR, mm) for maize crop at Tsalapitsa experimental field, an alluvial soil of small total available water TAW=116 mm m-1, 1951-2004.

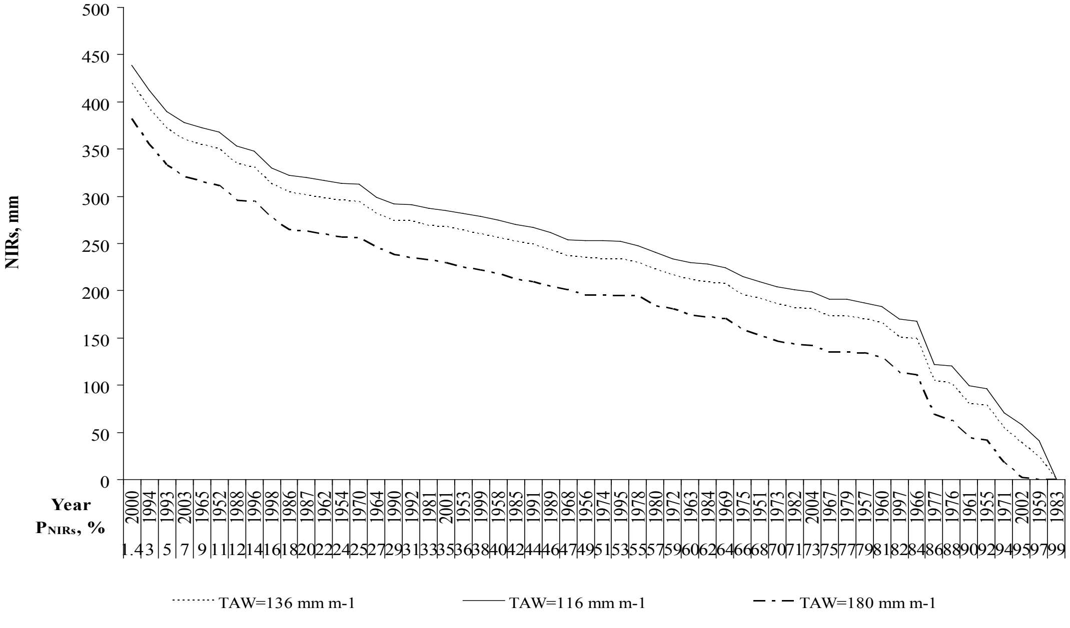
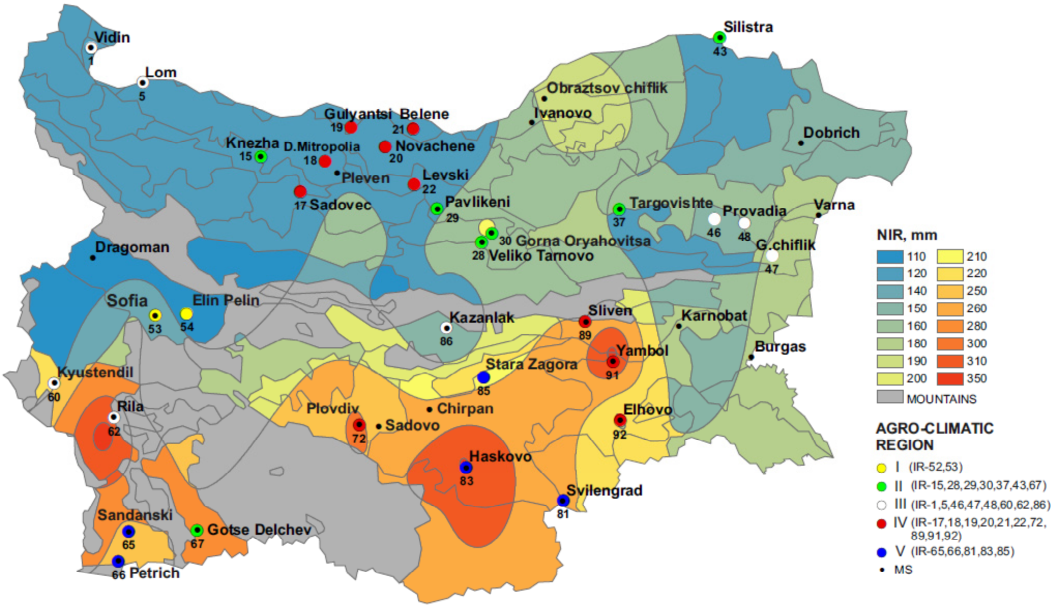
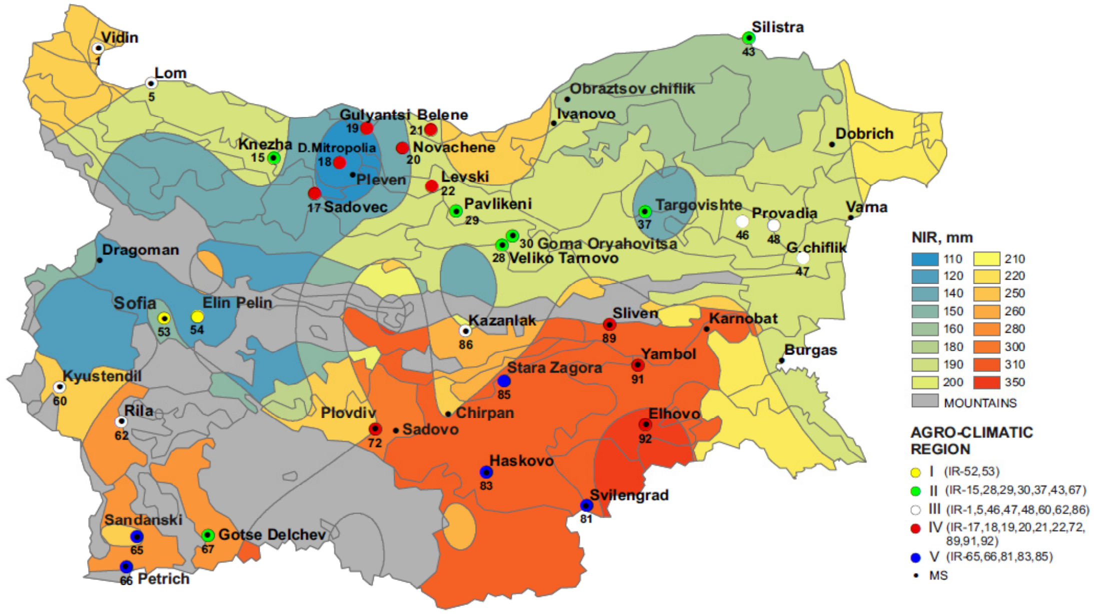


Figure 2. Probability curves of occurrence of a Net Irrigation Requirement (NIR, mm) for maize crop as influenced by small, average and large Total Available Soil Water TAW (mm m-1), Plovdiv, 1951-2004.



a) an "average" 1970



b) a "moderately dry" 1981

Fig. 3. Map of Meteorological Stations MS (.), Unified Irrigation IR (Zahariev et al., 1986) and Agro-Climatic AC Regions (🟡, 🟢, ○, 🔴, 🔵) (Tables 1 and 2) and Net Irrigation Requirements of maize (NIR,mm) relative to: a) an "average" 1970; b) a "moderately dry" 1981 and c) the "extremely dry" 2000, 1951-2004.

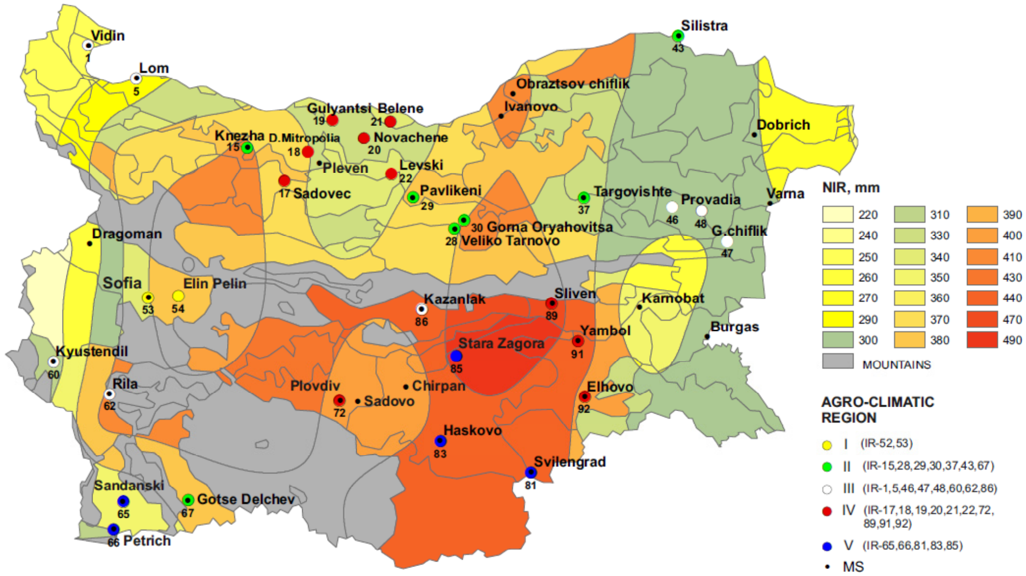


Fig. 3 c) the "extremely dry" 2000, 1951-2004.

The main difference between methodology presently developed and that of Zahariev et al. (1986) is the number of irrigation regions, for which NIR has been defined for. Regarding "Zahariev", their number is 97 while our results are related to only five unified Agro-Climatic regions and three soil groups in terms of soil water holding capacity. In this way, the information derived by the proposed methodology consists of only one page per crop (Table 1). Thus, if 31 crops are considered, including the Methodology section, 35 pages will be required instead of more than 640 p. in the "Zahariev" book. Such a multiple reduction of information on net irrigation requirements will facilitate considerably its use and practical application.

An advantage of the developed methodology is also the built probability curves of occurrence of a NIR within the range 2 %< P_I <98 %, such as the book of "Zahariev" does not comprise. That sort of NIRs provides an opportunity to evaluate the economical income of irrigation all over the range of climate variability and change in this country (Popova et al., 2014; 2015). In addition, maps of spatial NIR distribution and unified Agro-Climatic regions relative to maize crop have been worked out.

Conclusions

- The book of Zahariev et al. (1986) provides information on seasonal irrigation depth relative to 31 crops and 97 Irrigation Regions (IR) at three levels of probability of occurrence of a depth, namely: 10, 25 and 50%. Data are based on empirical results relative to the period 1950-1980 and had been used in design and exploitation of national irrigation systems till 1990.
- On the basis of data on present climate (1951-2004) and three groups of soil, Net irrigation requirements NIR relative to maize crop are determined by using the previously validated WinISAREG simulation model. Climate variability and change during the specified period have been accounted for.
- A methodology that defines net irrigation requirements for maize relative to five unified Agro-Climatic regions of this country and three levels of total available soil water is developed. Irrigation regions' unification is based on average reference evapotranspiration totals $ET_{0\ July-Aug}$ computed by the Penman-Monteith-FAO56 equation.
- Regarding the remaining irrigated crops, the number and cover of the specific Agro-Climatic regions as well as value of the respective average ET_0 totals will be different.
- Net Irrigation Requirement in table 1 is presented within the range 10 %< P_I <90 % of probability of occurrence of a NIR. That makes possible to build probability of exceedance curves for NIR in the whole range of present climate variability and change in Bulgarian plains.
- Created maps of Net Irrigation Requirement and unified Agro-Climatic regions visualize finding of the study.
- Considering the imposed objectives, the accuracy of net irrigation requirements found by the developed methodology is completely satisfactory. At the same time, it reflects the impact of present climate uncertainties. Multiple reduction of the volume of information facilitates its use in design and exploitation of the national irrigation systems.

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