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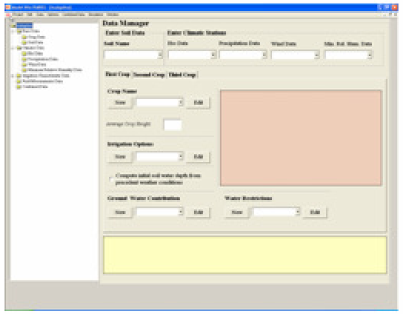
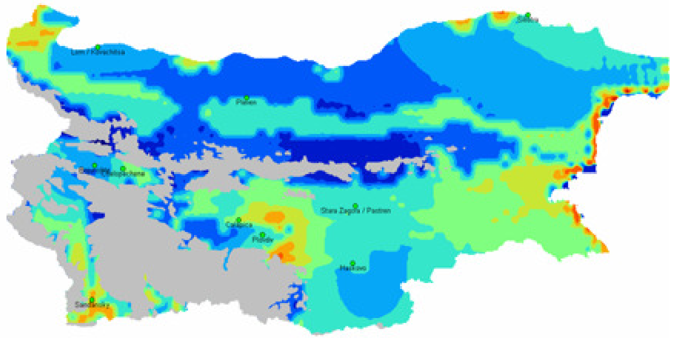
RISK ASSESSMENT OF DROUGHT IN AGRICULTURE, IRRIGATION MANAGEMENT AND DROUGHT MONITORING THROUGH SIMULATION MODELS





Jointly for our common future

-***ISSNP*** Institute of Soil Science “Nikola Poushkarov” (Bulgaria)

- ***UNSFA*** University of Novi Sad, Faculty of Agriculture, Department of Water Management (Serbia)
- ***NIMH*** National Institute of Meteorology and Hydrology (Bulgaria)
- ***HI-M*** Biotechnological Faculty and Hydrometeorological Institute of Montenegro
- ***HMS*** Hydrometeorological Service of Republic of Macedonia
- ***EARS*** Environmental Agency of the Republic of Slovenia
- ***AUA*** Agricultural University of Athens (Greece)

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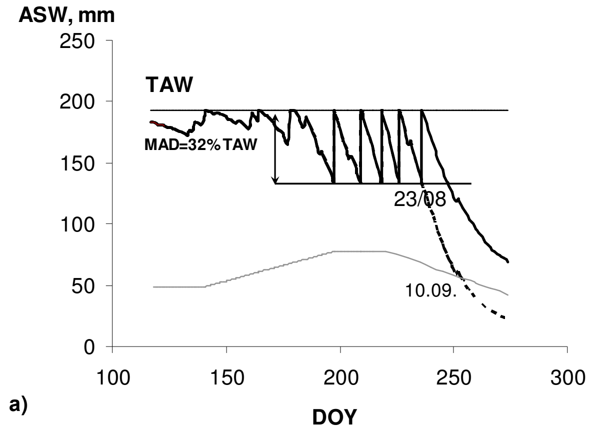
Aim: to improve drought preparedness (by risk assessment and establishing early warning system) and consequently help to reduce drought impacts.

Specific activities:

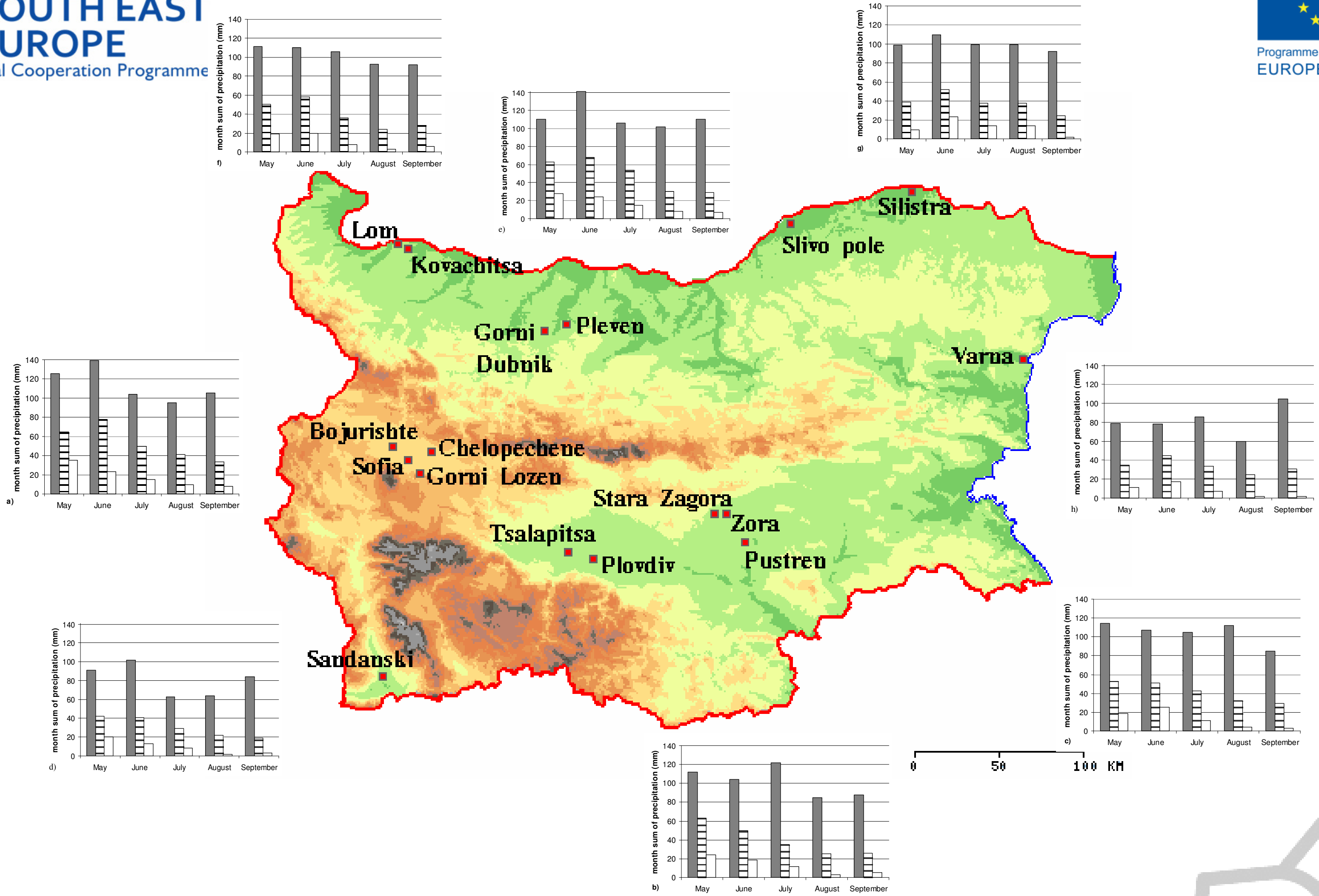
- Preparation of regional drought monitoring, analysis and early warning products;
- Assessment of vulnerability to drought impacts;
- Promotion and improved drought preparedness (30 reports in proceedings of international scientific conferences; 29 articles in national and international scientific journals; 3 popular articles and 1 monograph).

WINISAREG model

- WINISAREG (Teixeira et al. 1992; Pereira et al. 2003) is a simulation tool for computing the soil water balance, generating alternative irrigation schedules and evaluating the respective impacts on crop yields. TW is separated in three zones: (i) excess (ii) optimum yield and (iii) water stress.
- ***TAW***$=z(\theta_{ППВ} - \theta_{ВЗ})$ (4)
- *Rmin* is a fraction of *TAW:*
- $Rmin = (1-p)*TAW$ (5)
- $\Delta ASW = (Pe + Vz + Ir + Gc - ETa - Dr)\ \Delta t$ (6)
- $ASW > TAW$:
- $Dr = ASW - TAW$
- $ETmax = Kc\ ETo$ **(12)**
- (Stewart 1976):
- $(1 - Ya/Ymax) = Ky\ (1 - ETa/ETmax)$ **(13)**



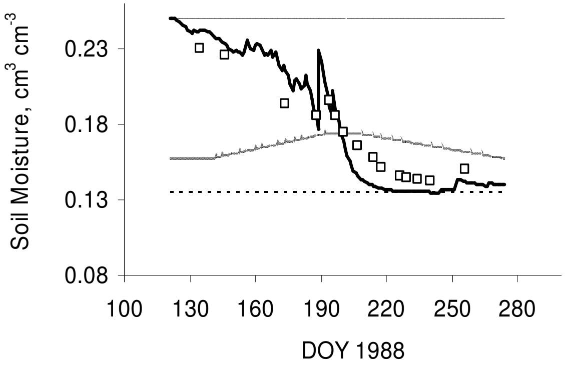
Bulgaria case study



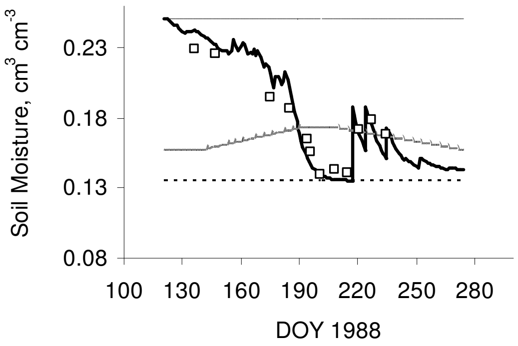
Experimental fields of *ISSNP* and meteorological stations of *NIMH*

Results

I. Calibration/validation of WinISAREG model Thracian Lowland, *ISSNP*



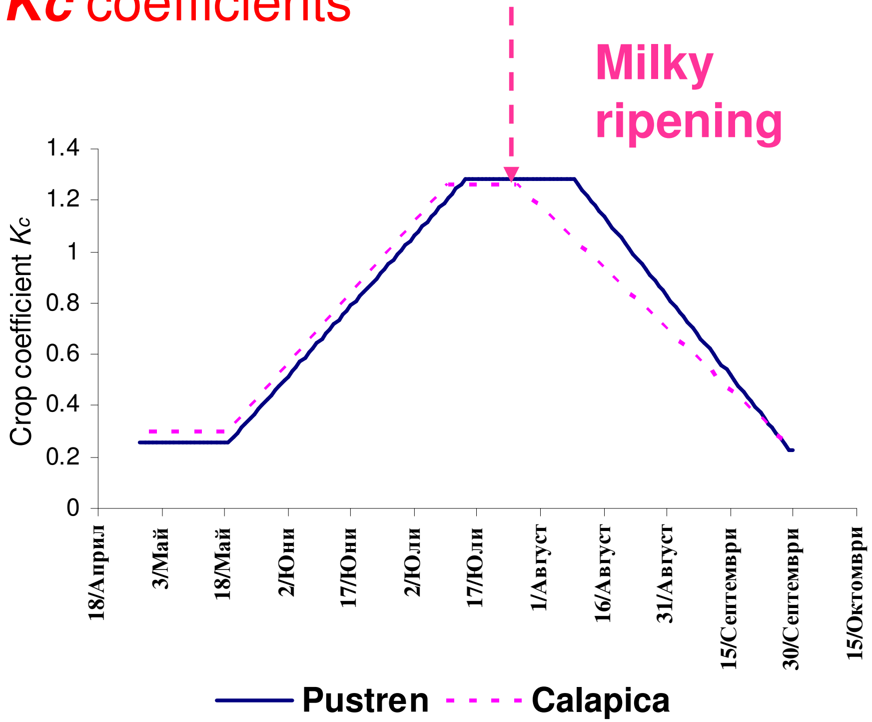
e)



f)

Observed and simulated SM versus time (1988)
model validation for high stress treatments 9 (e) and 11 (f)
alluvial soil (116 mm m -1), Tsalapitsa, Plovdiv region

Kc coefficients



Jointly for our common future

I. Calibration/validation of WinISAREG model
Kc coefficients, Sofia field, *ISSNP*

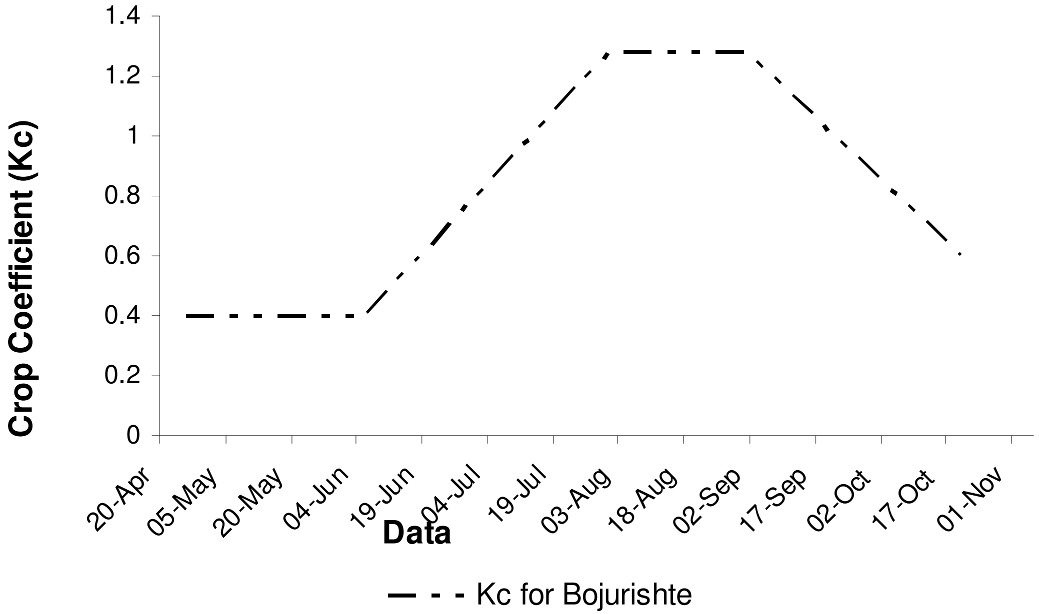


Fig.5. Crop coefficients for maize at Bojurishte, model calibration, 2004

Table1. Statistical parameters relative to the model predicted θ (soil water content) during calibration (2004) and validation (2003, 2005r) of the model, Bojurishte site, Sofia field.

Year	b	R2	RMSE, cm3cm-3	AAE, cm3cm-3	ARE, %	EF	dIA
2004, calibration	1.00	0.88	0.029	0.014	3.11	0.87	98
2003, validation	0.99	0.66	0.020	0.020	4.55	0.69	92
2005, validation	1.02	0.58	0.015	0.022	5.15	0.65	88

Table 2. Dates limiting the main crop development phases, Kc and p for maize, Bojurishte site, Sofia field, 2004.

Phenophases	Initial state	Mid season	Ripening
Date	05/05 - 06/06	01/08 - 01/09	20/10
Kc	0.40	1.28	0.60
p	0.46-0.75	0.60	0.78

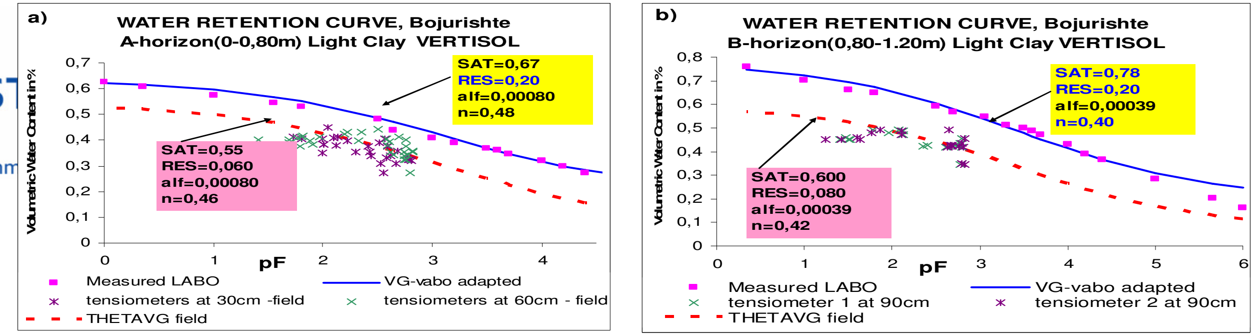


Fig.2. Adjusment of laboratory WRC (full line) to field observations, dashed line, relative to: a) A-horizon and b) B-horizon, Bojurishte site.

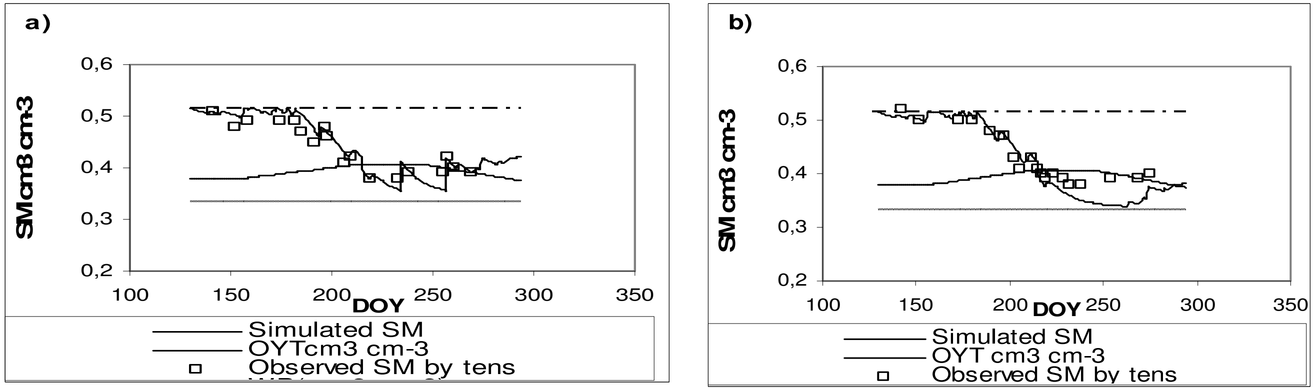
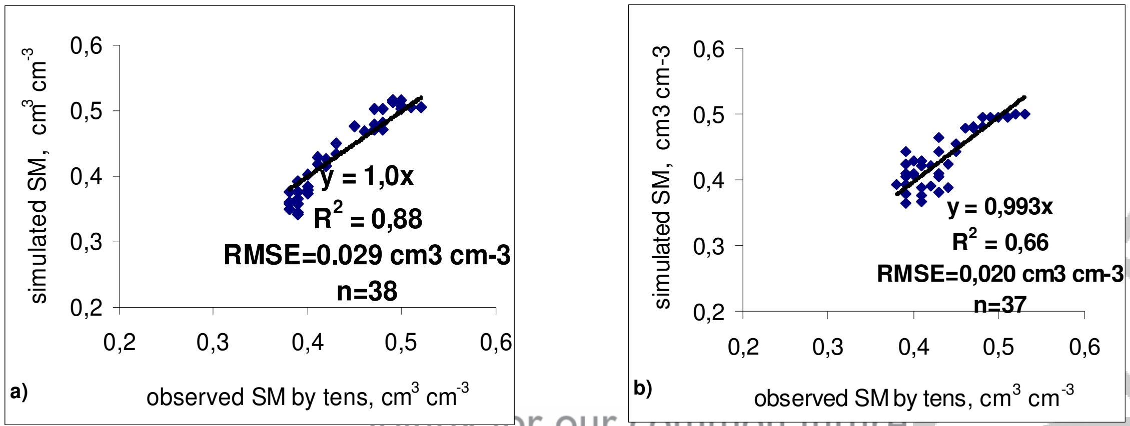


Fig.3. Field observations (□) and ISAREG simulation (-) of SM, cm3 cm-3, 2004: a)irrigated and b) rainfed maize, Bojurishte , Sofia field.

Fig.4 Comparing simulated and observed SM (cm3 cm-3) for the year of: a) calibration (2004r) and b) validation (2003), irrigated rainfed treatment; Bojurishte, Sofia field.



I. Calibration/validation of WinISAREG model to compute RYD, Thracian Lowland

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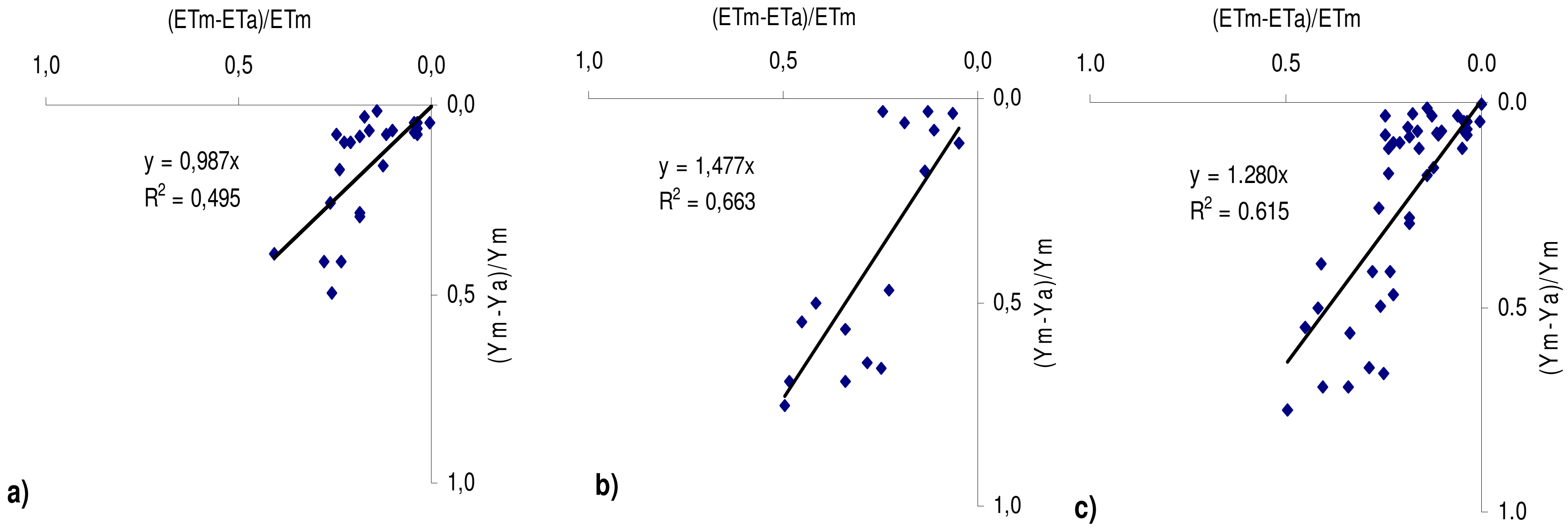
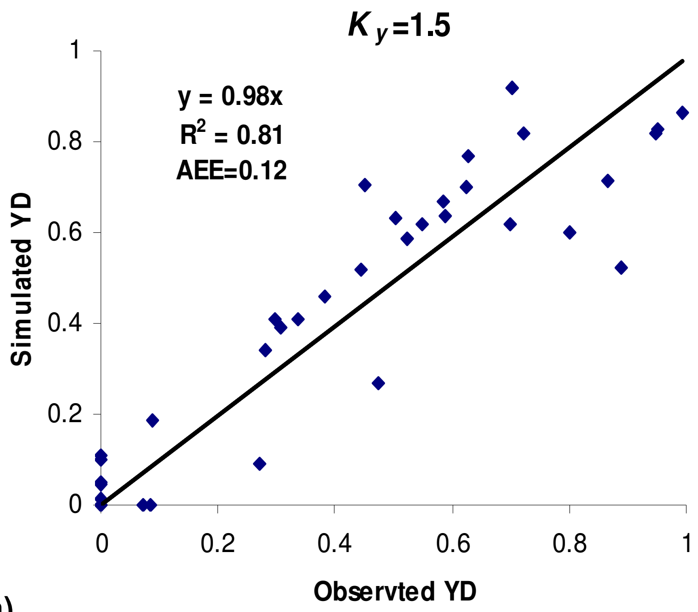
Deriving Ky using long-term data from Pustren site, *ISSNP*:

a) ***Kn-2L-611***, 1972-1980г AEE=0.048;

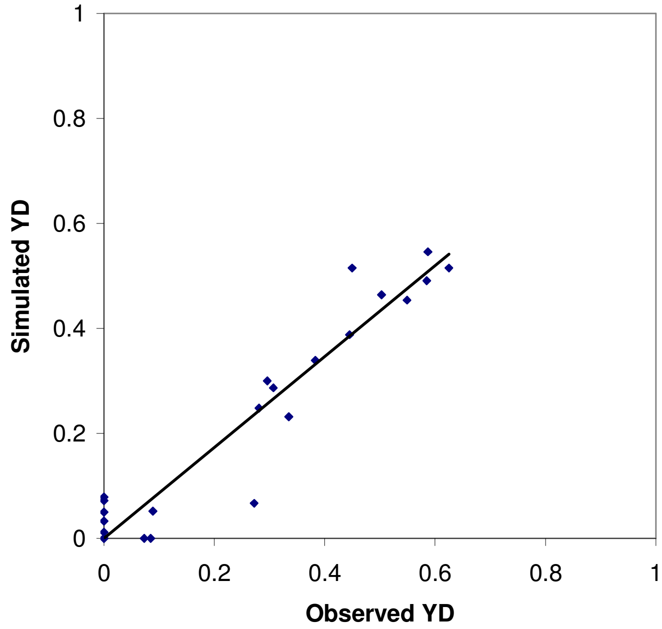
b) ***H-708***, 1981-1990г AEE=0.067; c) both hybrids, 1972-1990г



Validation of Ky (H708) using long-term irrigation data
Tsalapitsa



a)



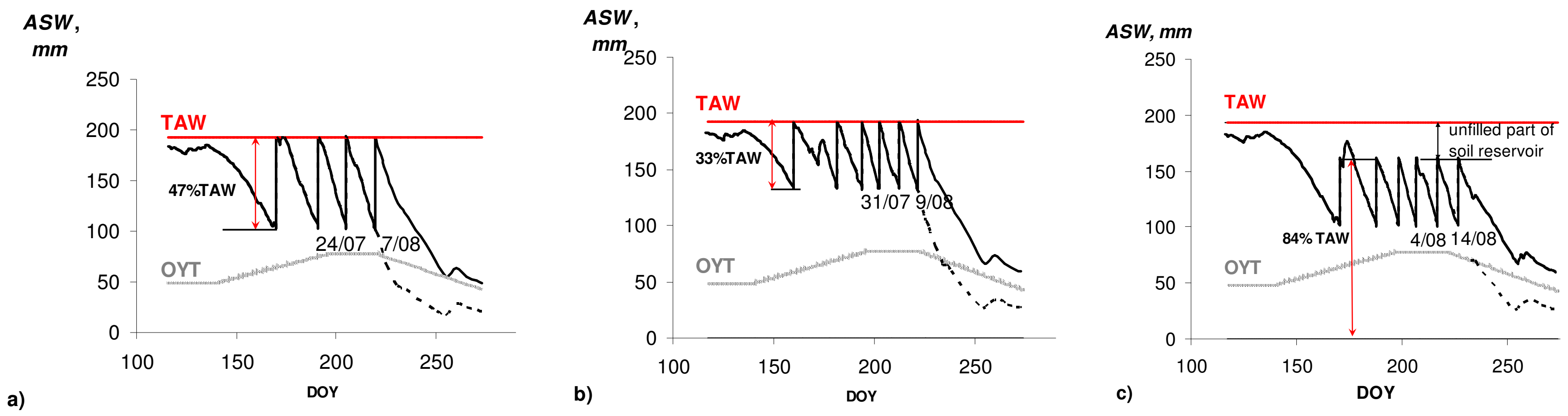
One-to-one simulated *versus* observed ***YD*** for the complete set of irrigation treatments, 1984-1991 (*Ky*=1.5);

The experimental data sets having a **(1-Ya/Ymax) < 0.5** and Ymax not affected by water stress (*Ky* = 1.32),

b = 0.87 R^2 = 0.91,AAE = 0.06

Results

II. Development of irrigation scheduling system for precise irrigation *ISSNP*



Simulation of ASW (mm) for 3 irrigation scheduling alternatives in the very dry 1981, Pustren (a vertisol soil), Stara Zagora:

a) alternative 1 for continuous-flow furrow irrigation;

b) alternatives 2 and;

c) 3 for surge-flow furrow /sprinkler irrigation with identification of the date of the last irrigation when aiming at maximum yield (the full line) and when the last irrigation event is skipped (the line in dashes).

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Results

II. Development of irrigation scheduling system for precise irrigation *ISSNP*

Programme co-funded by the EUROPEAN UNION

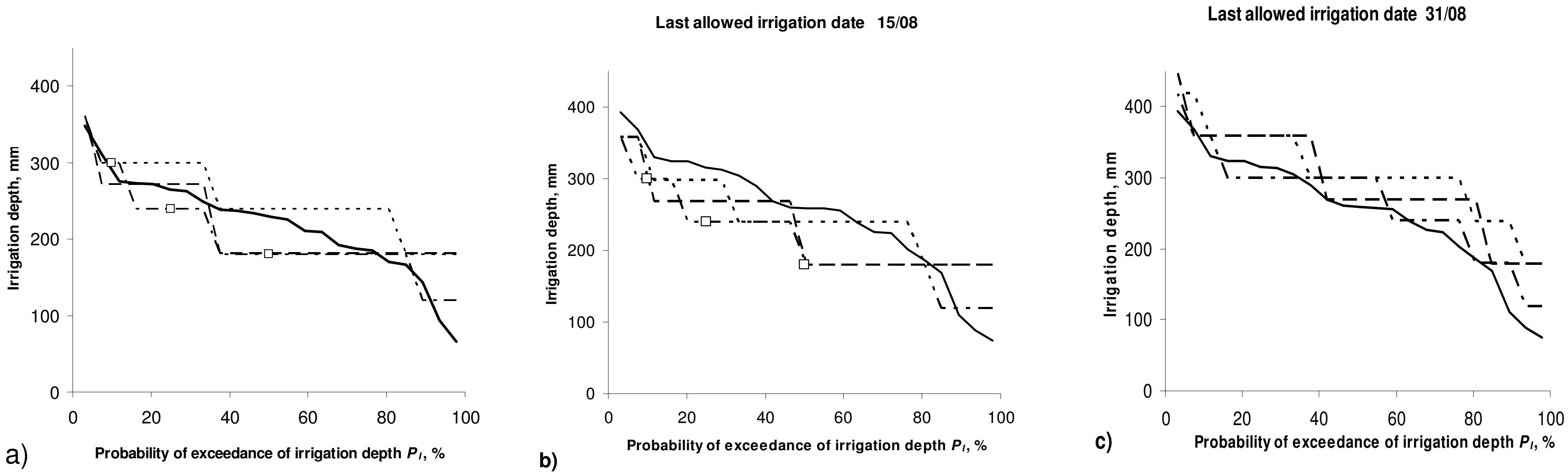

Fig. 18. Probability curves of NIR (▬▬) and ID for the irrigation scheduling alternatives 1 (– –), 2 (▪ ▪ ▪ ▪ ▪) and 3 (–·–·), and currently adopted scheduling (□) relative to two sites: a) Pustren and

b) Zora when the last allowed irrigation date is 15/08

or c) 31/08 (Zora), 1970-1992

Results

II. Development of irrigation scheduling system for precise irrigation *ISSNP*

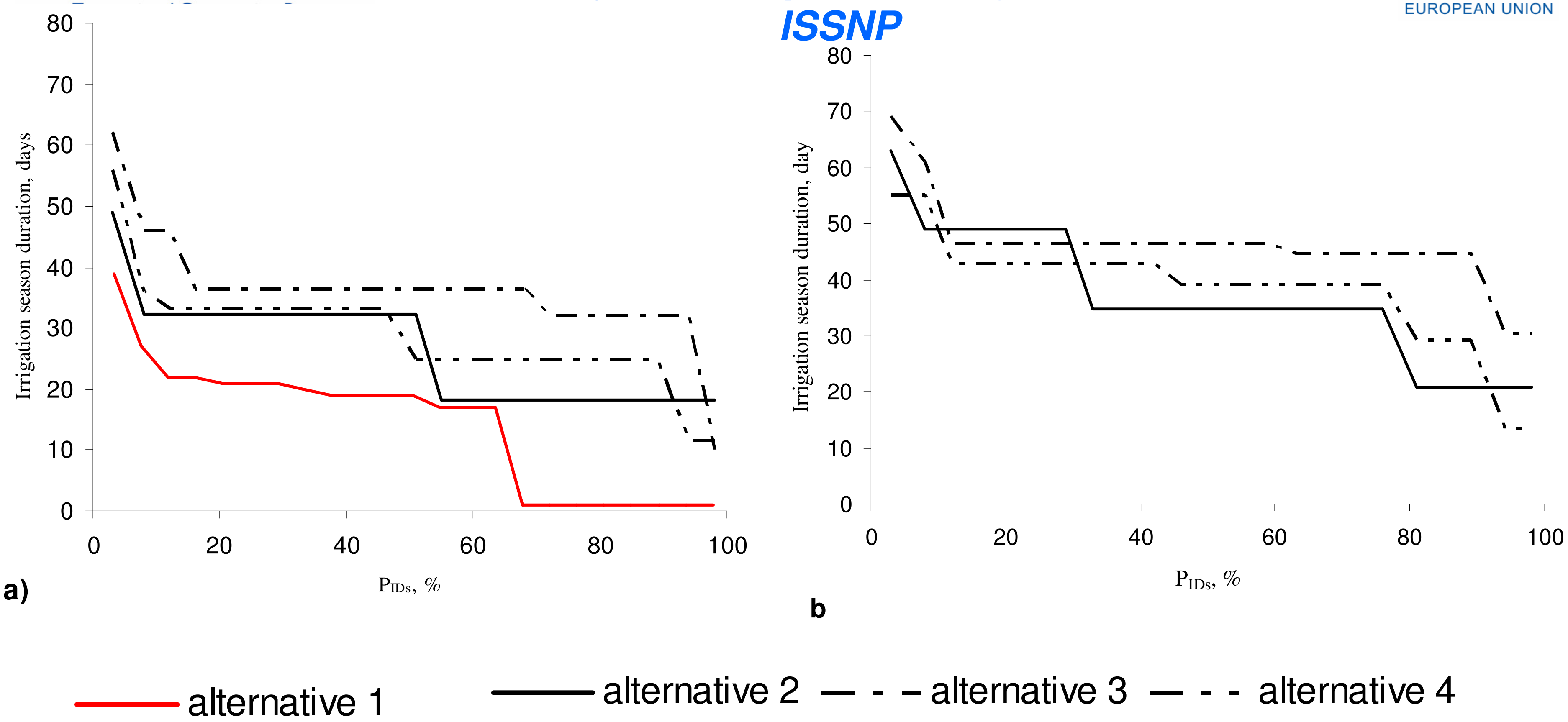

Figure 6. Comparison of irrigation season duration (ISD) probability curves for three irrigation scheduling alternatives at sites: a) Pustren, a vertisol;

b) Zora, a chromic cambisol, Stara Zagora, 1970-1992.

Results

I. Calibration/validation of WinISAREG model Thracian Lowland, *HMS* –FYROM

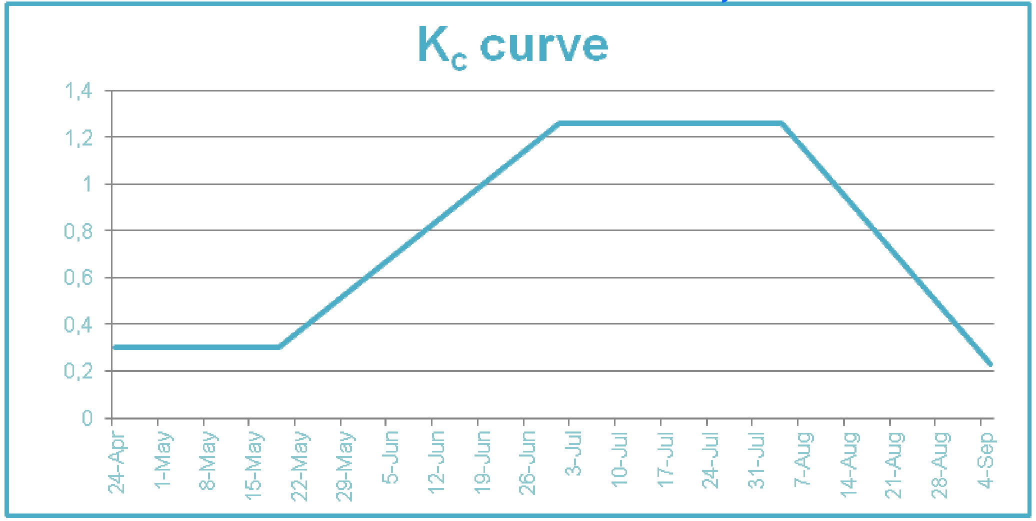

Figure 1: Crop coefficient curve for maize FAO 500 for 2003, Butel, Skopje

Growth phases	Initial period	Mid season period	End season period
Dates	24.04-19.05	01.07-04.08	05.09 (harvest)
K_c	0.30	1.26	0.23
P	0.80	0.66	0.80

Table 1: Dates of crop development stages and model calibration parameters: crop coefficient K_c and soil water depletion fractions for no stress p for maize at Butel, Skopje

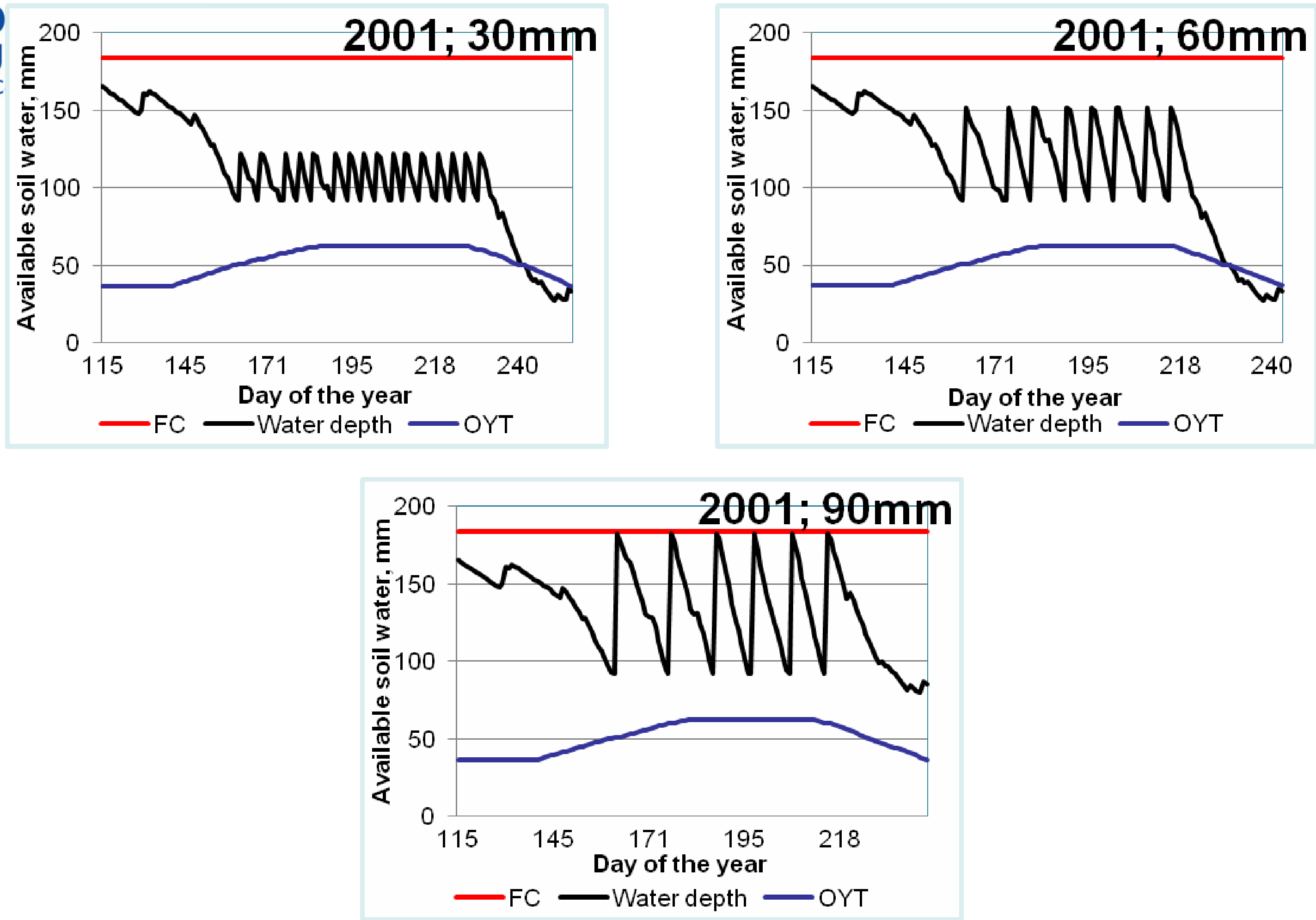

Figure 2: Simulation of ASW for three irrigation scheduling alternatives in 2001 for maize in Butel, TAW=180 mm m -1, Skopie field
The red line corresponds to TAW and the blue line to the non stress threshold.

II. Development of irrigation scheduling system for precise irrigation *HMS*

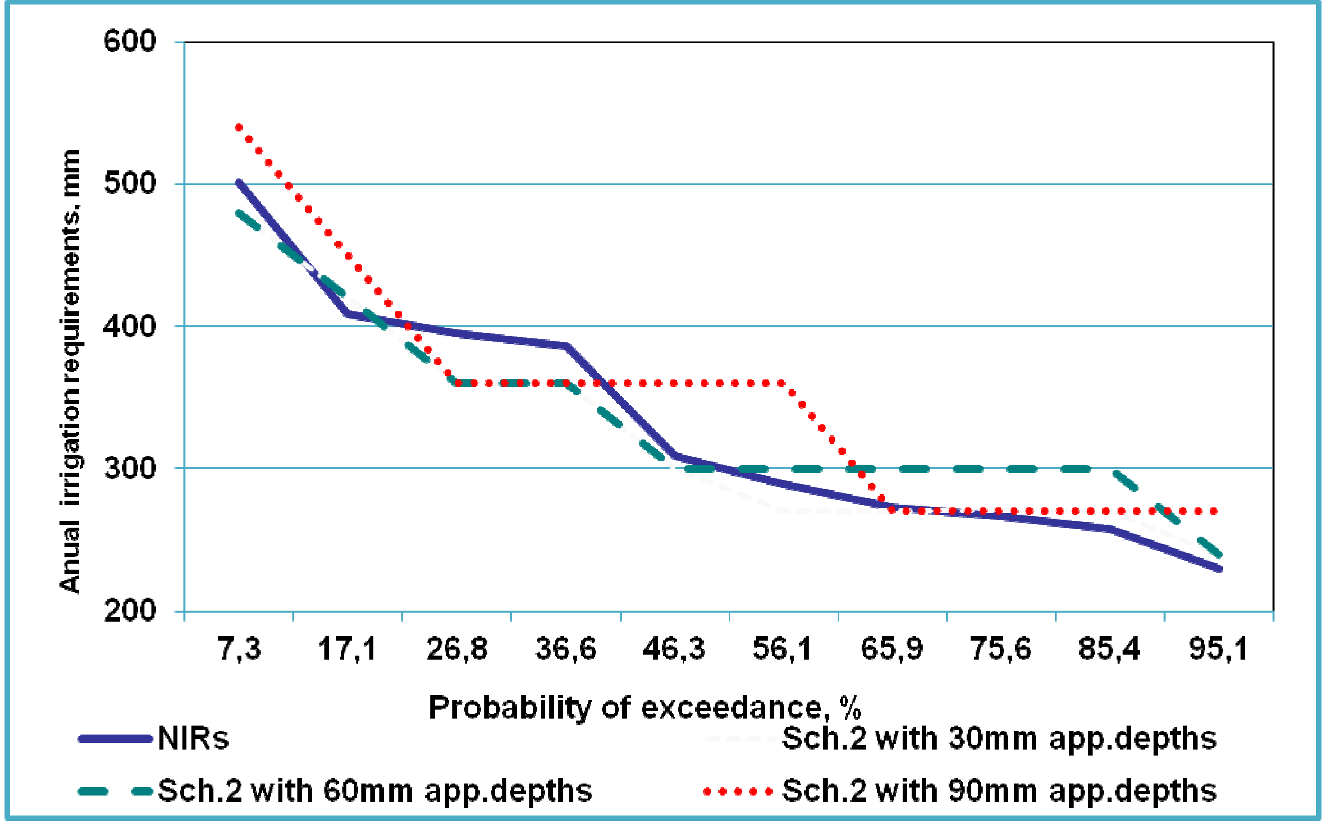

Figure 2: Probability curves of Net irrigation requirements (NIRs, mm) and demands (IDs), for 30mm (a), 60mm (b) and 90mm (c), Butel, Skopie, 2001-2010

UNSFA – a case study for Serbia

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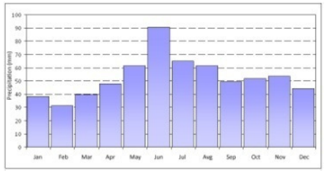
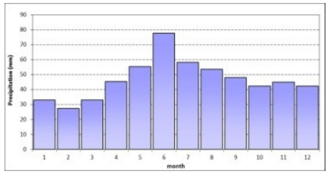
Climate characteristics

Average monthly precipitation (1971-2010)

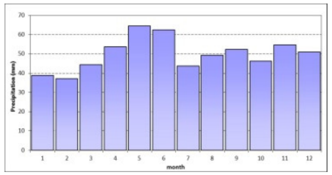
Geographic location of chosen sites



Rimski Sancevi



Kikinda



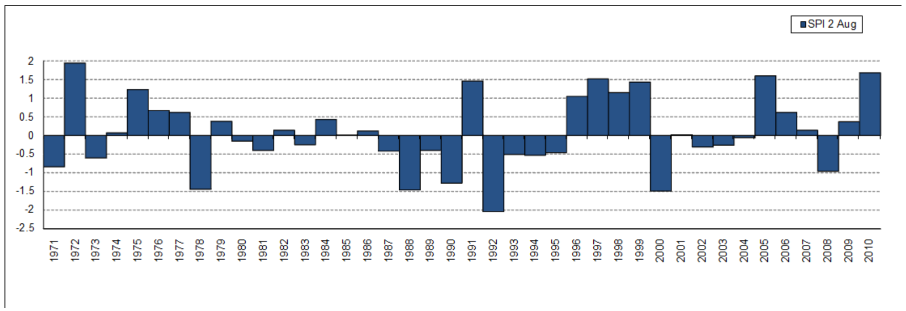
Nis

Crop data

Hybrid NS640;

Kcmid=1.2 (15/07-5/08)

Kcend=0.6 (30/09-10/10)



High Peak Season "July-August" SPI2, Rimski Sancevi

Soil characteristics

A Calcareous Chernozem Soil on the Loess Terrace, **TAW = 146 mm·m^{-1}**
Rimski Sancevi (Belic et. al, 2003)

Horizon	Depth (m)	Sand (%)	Silt (%)	Clay (%)	FC (%)	WP (%)	TAW (%)
Ap	0.22	40.58	35.25	24.17	27	11.7	15.3
A	0.59	39.62	33.67	26.71	31.8	19.7	12.1
AC	0.94	39.60	38.09	22.31	27	11.7	15.3
C	1.65	38.53	40.55	20.65	27	11.7	15.3

A Chernozemlike Calcareous Meadow Soil on Loess Plateau, **TAW = 108 mm·m^{-1}**
Rimski Sancevi (Zivkovic et al., 1972)

Horizon	Depth (m)	Sand (%)	Silt (%)	Clay (%)	FC (%)	WP (%)	TAW (%)
Ap	0.2	64	19.8	16.2	20.7	9.5	11.2
A	0.4	56.8	23.8	19.4	25.5	14.8	10.7
AC	0.85	58.2	21.2	20.6	25.5	14.8	10.7
C	1.5	57.4	20.2	22.4	25.5	14.8	10.7

A Vertisoil soil, **TAW=156 mm·m^{-1}** , Nis

Horizon	Depth (m)	Sand (%)	Silt (%)	Clay (%)	FC (%)	WP (%)	TAW (%)
A_{mo}	0.7	20	40	40	44	26	18
AC	1.2	30	25	45	45	31	14
C	1.8	25	25	50	45	31	14

A Chernozem Limeless soil on sand, **TAW=140 mm·m^{-1}** , Kikinda

Horizon	Depth (m)	Sand (%)	Silt (%)	Clay (%)	FC (%)	WP (%)	TAW (%)
A	0.6	45	30	25	27	11.7	15.3
AC	1.2	35	40	25	27	11.7	15.3
C	2.0	35	25	40	31.8	19.7	12.1

II. Development of irrigation scheduling system for precise irrigation, *UNSFA*

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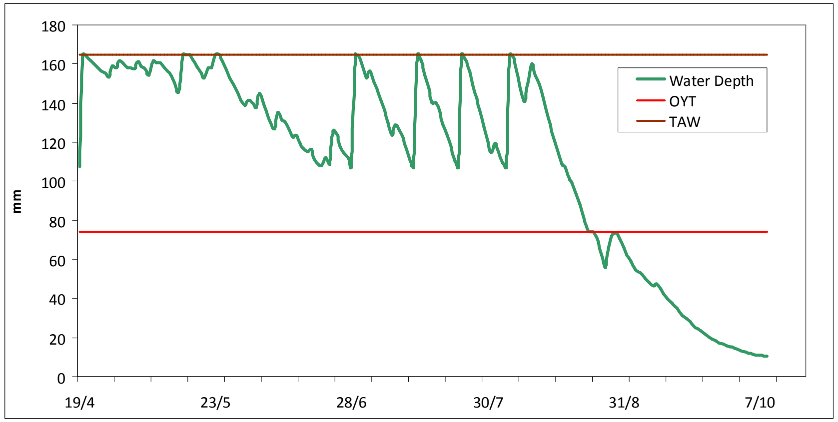
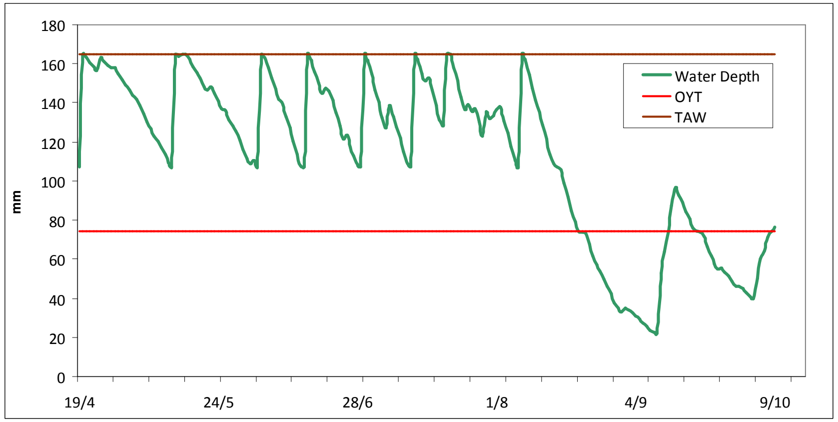
Kikinda (TAW=140 mm m $^{-1}$)

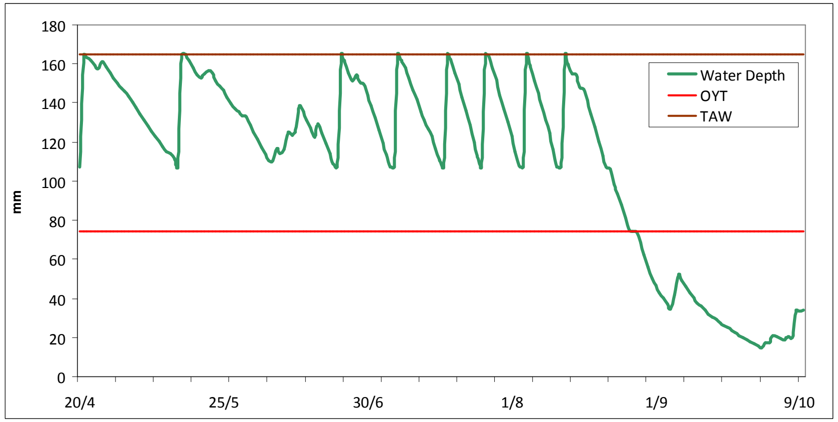
Alternative 3 (60 mm)



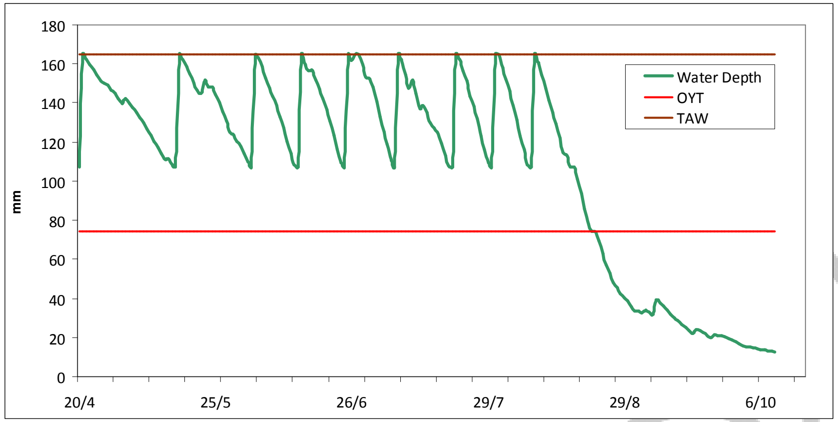
Soil water graph, an average year 1985 (P_{NIRs}=51%)



Soil water graph, a moderately dry year 2003 (P_{NIRs}=85%)



Soil water graph, a very dry year 1992 (P_{NIRs}=95%)



Soil water graph, a very dry year 2000 (P_{NIRs}=98%)

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II. Development of irrigation scheduling system for precise irrigation, *UNSFA*

Nis (TAW=156 mm m $^{-1}$)

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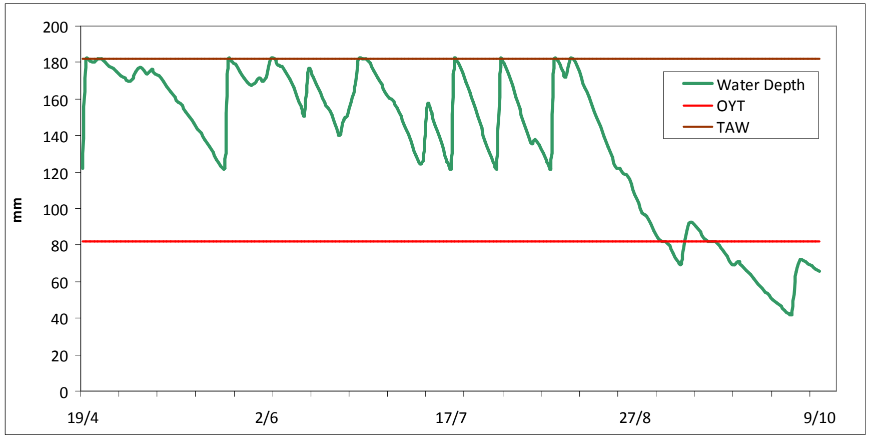
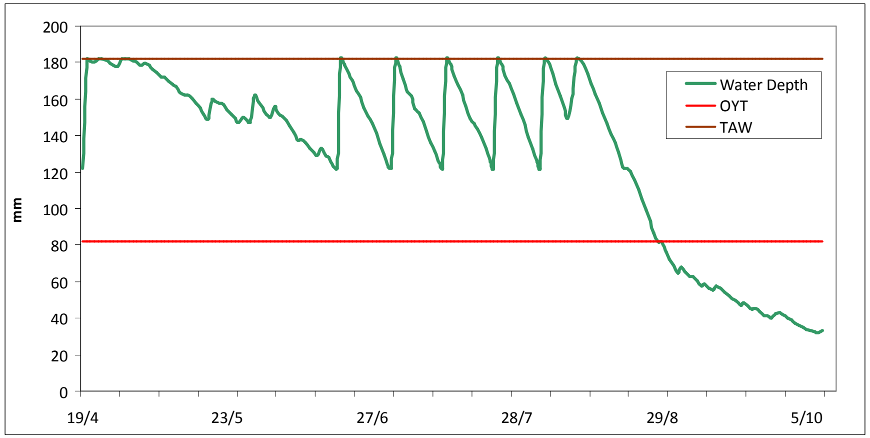
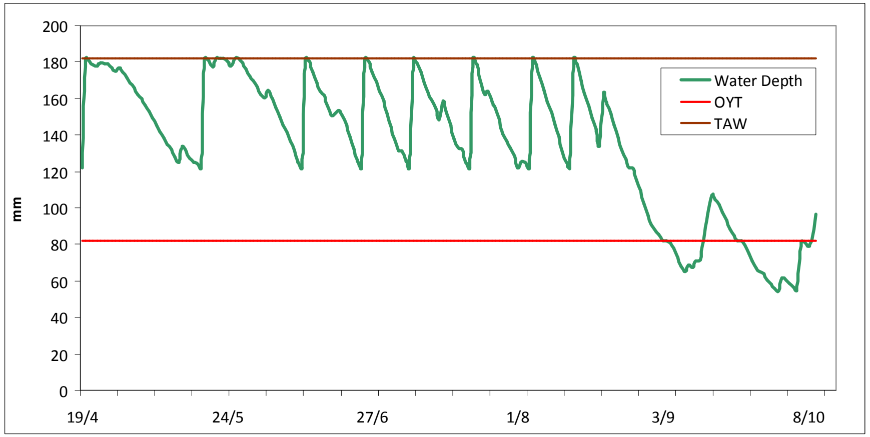


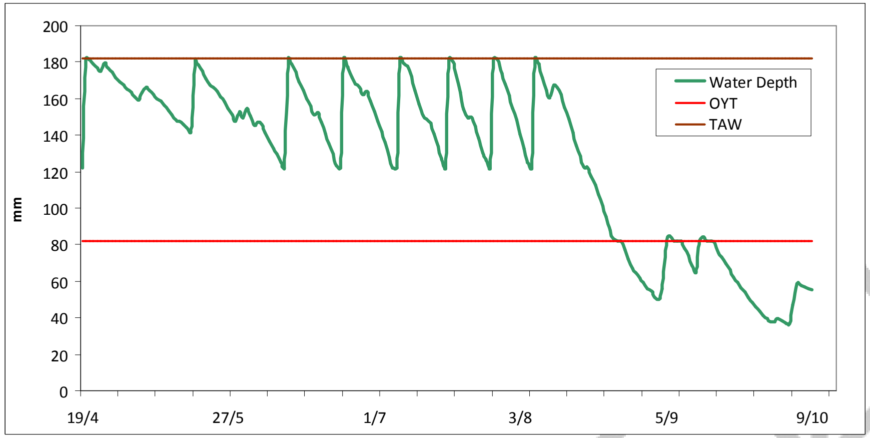
Soil water graph, an average year
2009 (P_{NIRs}=51%)



Soil water graph, a moderately dry year
1990 (P_{NIRs}=85%)



Soil water graph, a very dry year 2003
(P_{NIRs}=95%)



Soil water graph, a very dry year 1993
(P_{NIRs}=98%)

AUA – a case study for Greece

Site characteristics

Current view of the area (the Copais Plain is distinguishable in the center of the map)

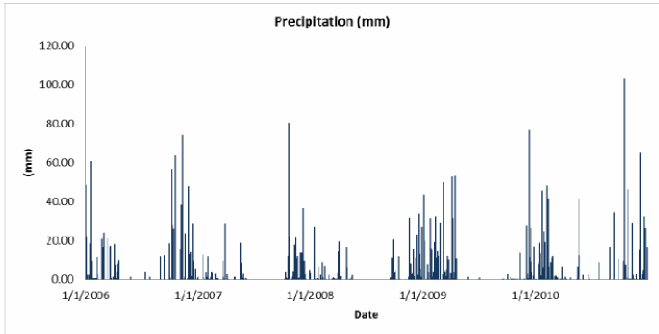


Fig. 8. Cumulative daily precipitation (1/1/06-31/12/10)

Climate characteristics

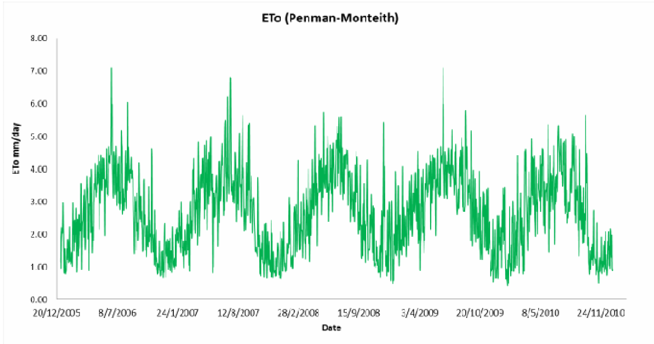


Fig. 5. Average daily ETo (1/1/06-31/12/10)

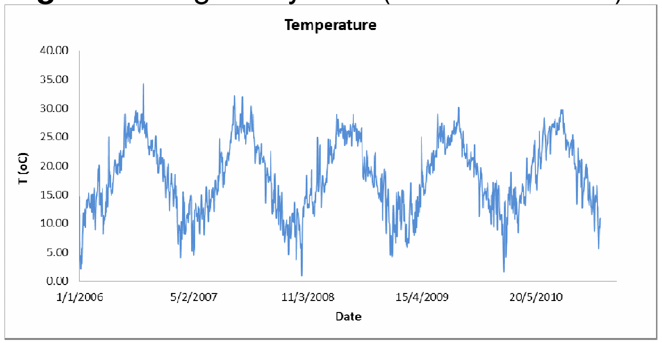


Fig. 6. Average daily air temperature (1/1/06-31/12/10)

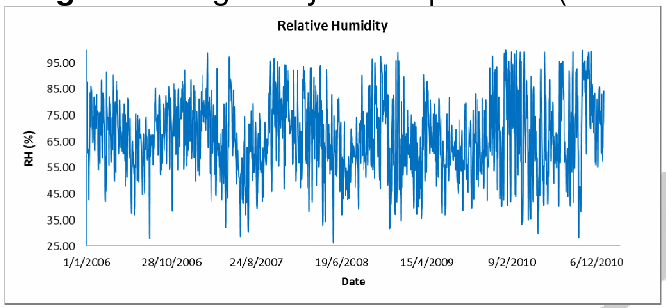


Fig. 7. Average daily relative humidity (1/1/06-31/12/10)

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II. Development of irrigation scheduling system for precise irrigation, *AUA*

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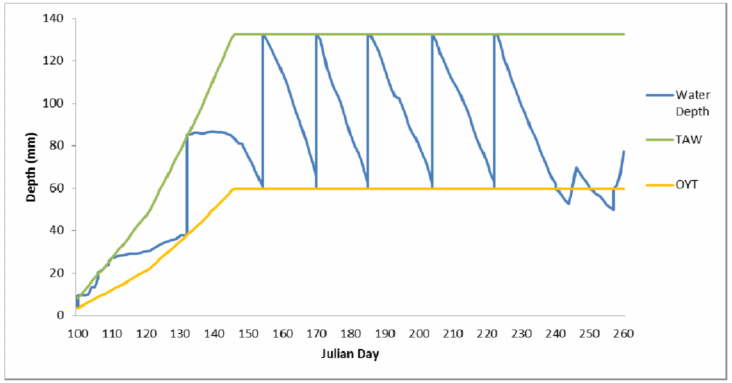
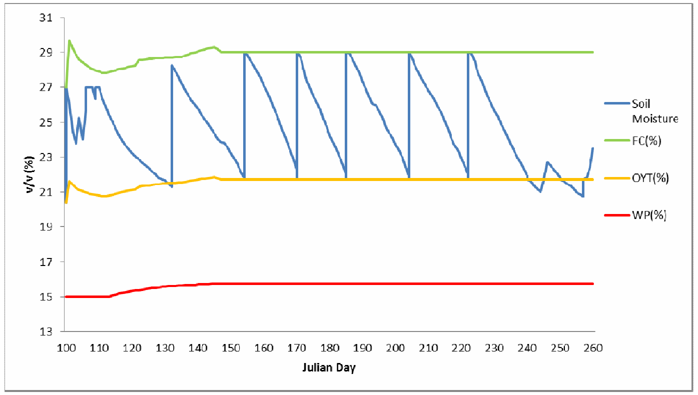
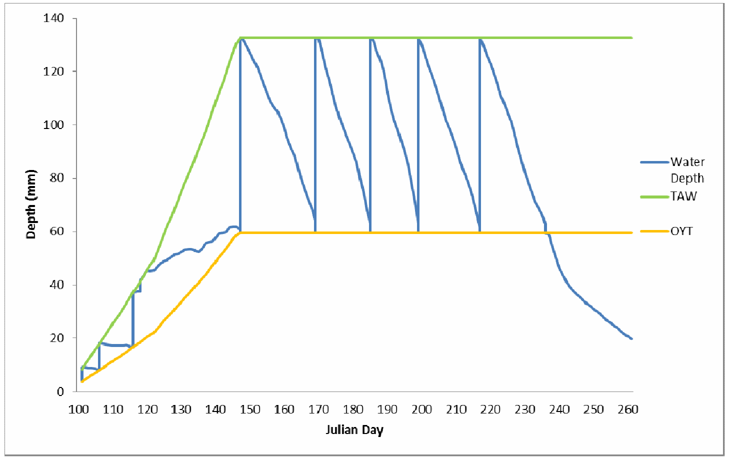
Copais, Beotia



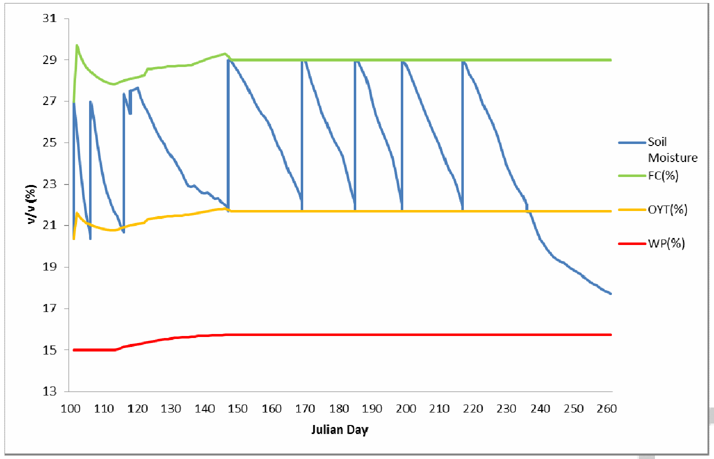
Soil Water Graph for year 2006



Soil Moisture Graph for year 2006 (the wettest)



Soil Water Graph for year 2008



Soil Moisture Graph for year 2008 (the driest)

Jointly for our common future

Results

III. Vulnerability of agriculture to drought , *ISSNP*

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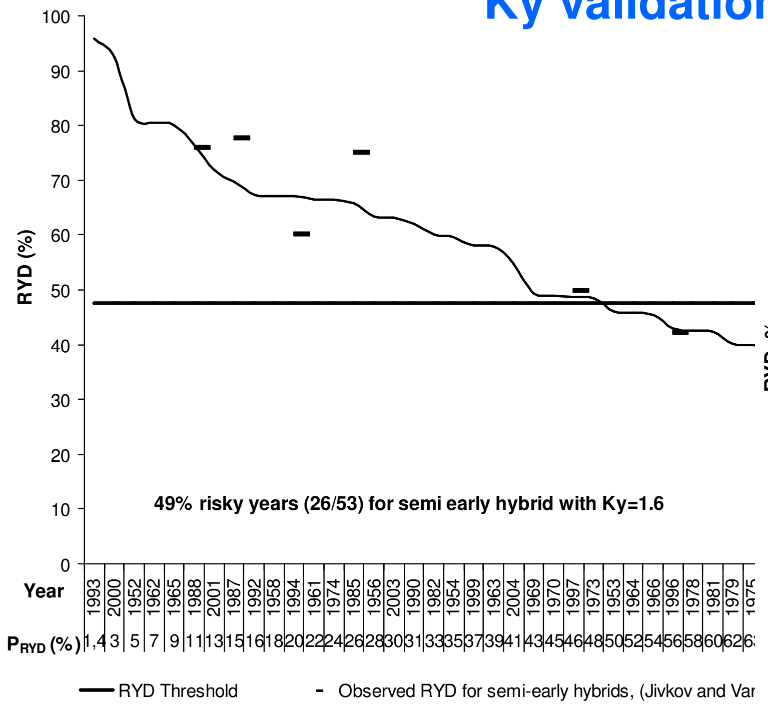
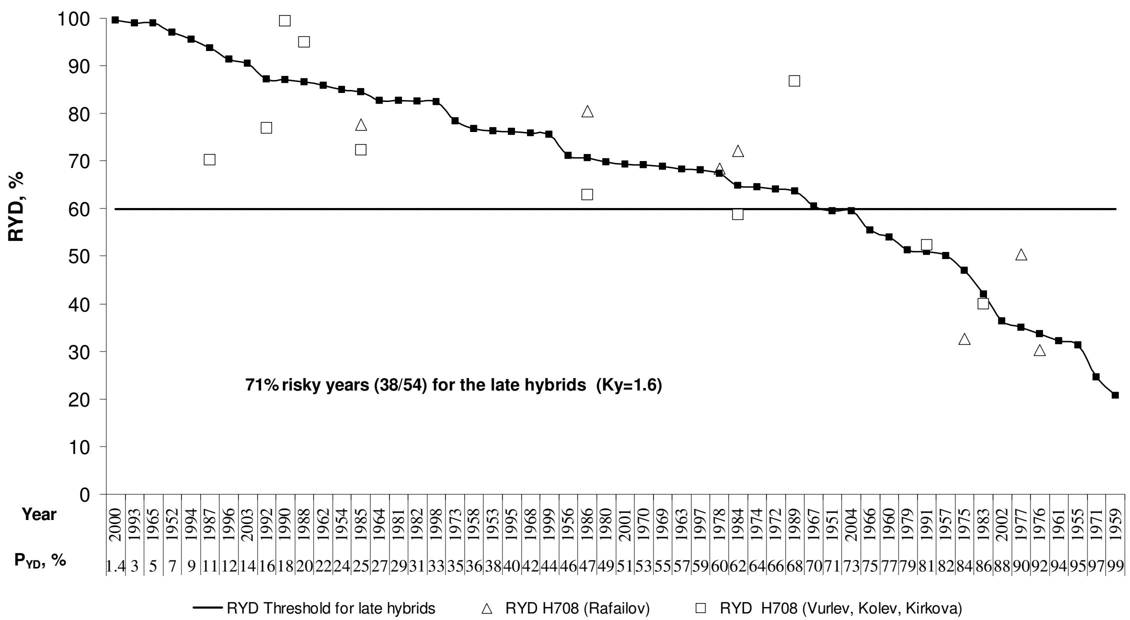
Ky validation for rainfed maize, TAW=116 mm m^{-1}





Probability of exceedance curves of RYD under rainfed maize
Ky=1.6 relative to soils of for: Sofia field

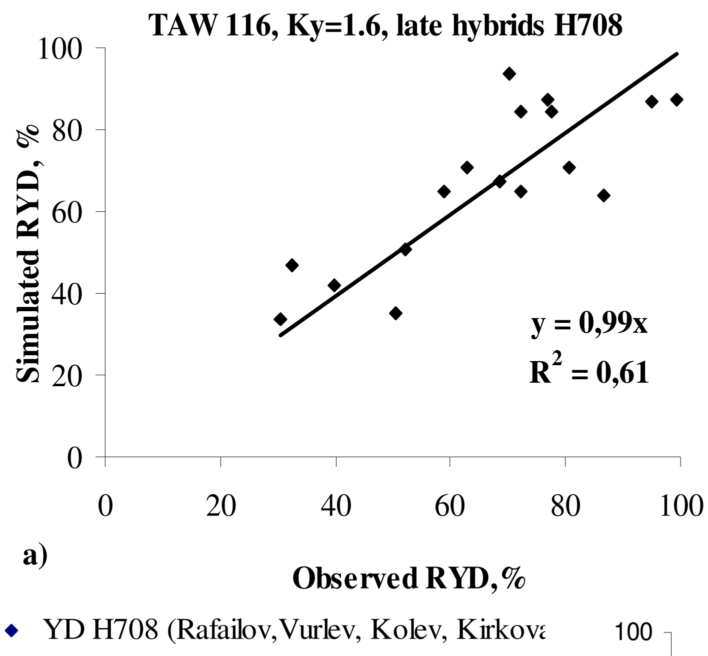
Experimental field Tsalapitsa, Plovdiv region, **1951-2004**

Jointly for our common future

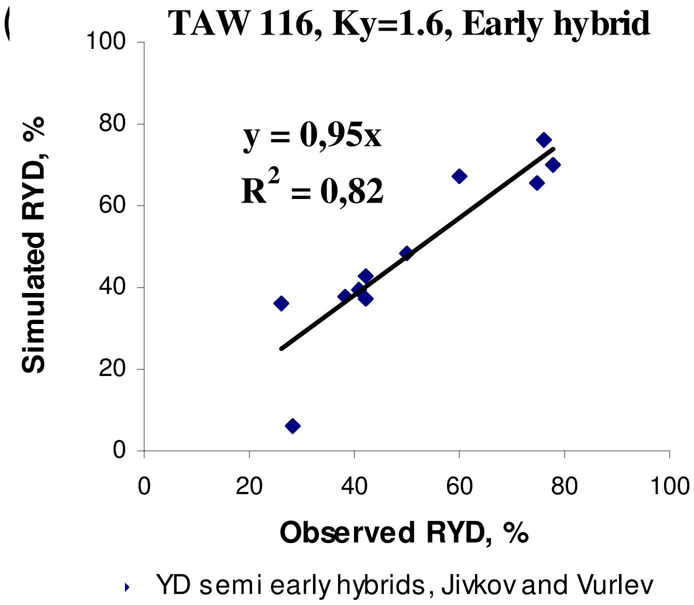
III. Vulnerability of agriculture to drought

Ky validation for rainfed maize, *ISSNP*

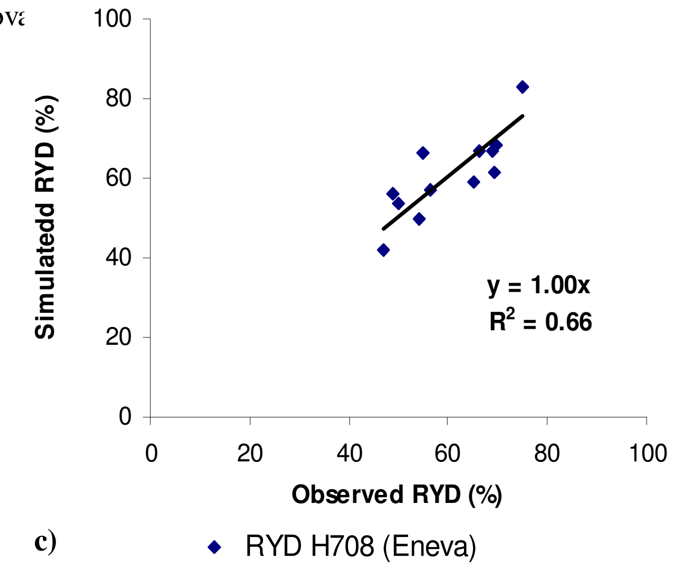
One to one regression between observed and simulated Ky=1.6 RYD (



(a) Tsalapitsa, Plovdiv



(b) Chelopechene, Sofia



(c) Pustren, Stara Zagora

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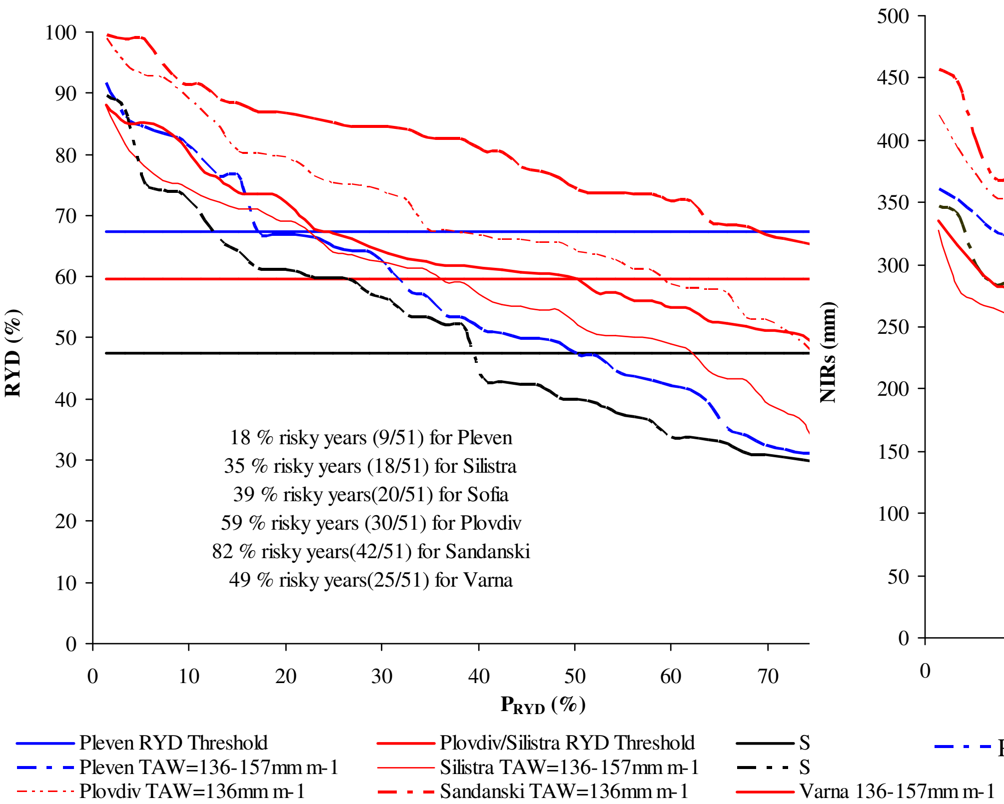
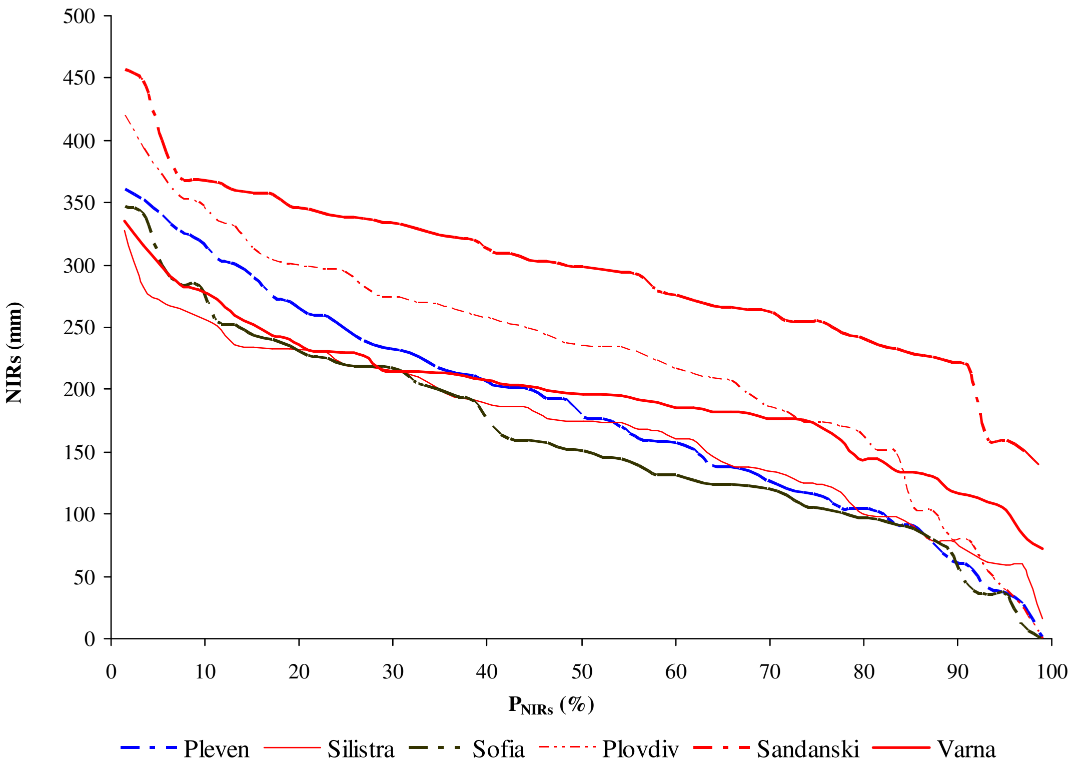
nmon future

Results

III. 4 and 5 Assessment of drought vulnerability for climate regions and soil groups in Bulgaria, ***ISSNP***

Yields of rainfed maize and risky years





NIRs, TAW (136-157 mm m^{-1}), 1951-2004

Results

III. 4 and 5 Assessment of drought vulnerability for climate regions and soil groups in Bulgaria, *ISSNP*

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Variability of rainfed maize grain yield characterized by the average value, kg ha-1, and the coefficient of variation Cv, %, climate regions and soil groups in Bulgaria, 1951-2004

	South Bulgaria								North Bulgaria			
	Sofia field		Thracian Lowland				Sandanski		Danube Plain			
	Sofia		Plovdiv		Stara Zagora		Sandanski		Pleven	Lom	Silistra	Varna
Climate region	Continental		Transitional continental				Transitional Mediterranean		Continental			Black sea
Maize hybrid	semi early		Late *(H708, 2L602, BC622)*									
TAW mm m^{-1}	Average Yield, kg ha^{-1}	*Cv*, %	Average Yield, kg ha^{-1}	*Cv*, %	Average Yield, kg ha^{-1}	*Cv*, %	Average Yield, kg ha^{-1}	*Cv*, %	*Cv*, %	*Cv*, %	*Cv*, %	*Cv*, %
116	4421	**42**	3894	**69**	3723	59	2292	**72**	50	55	46	50
136-157	4920	37	4550	59	4299	52	2906	59	44	47	40	42
180	5896	**29**	5915	43			4250	41	34	35	30	30
173					5483	41						

Jointly for our common future

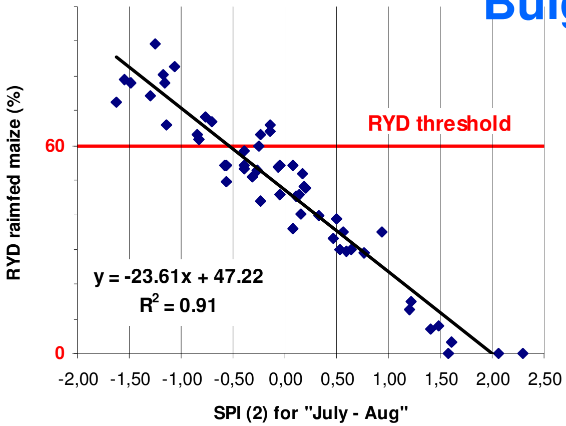
Results

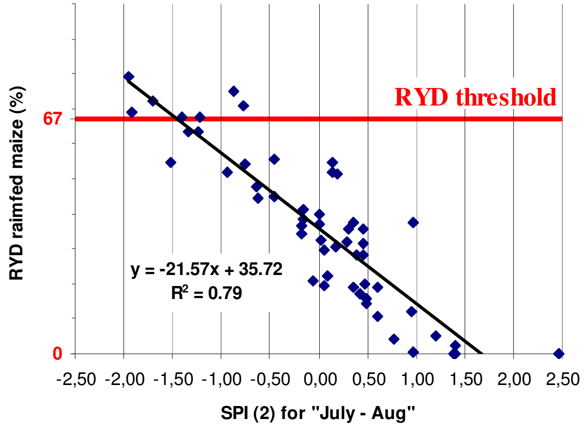
III. 4 Drought vulnerability categories according to climate region and soil group Bulgaria

Plovdiv and

Pleven,

TAW=180 mm m^{-1}





Economical threshold of High Peak Season SPI2 "July-Aug" (the average SPI2 for July and August) indicating the risk relative to rainfed maize for each climate region/soil group in Bulgaria

Climate Region		Soil groups according to total available water *TAW:*		
		Small 116 mm m^{-1}	Medium 136-157 mm m^{-1}	Large 173-180 mm m^{-1}
Transitional Mediterranean	**Sandanski**	+1.40	+1.00	+0.20
Transitional Continental	**Stara Zagora**	+0.50	+0.10	-0.50
	Plovdiv	+0.15	0.00	-0.50
Moderate Continental	**Lom**	+0.15	-0.10	-0.75
	Sofia	0.00	-0.25	-0.90
	Silistra	-0.15	-0.50	-1.25
	Pleven	-0.50	-0.75	-1.50
Northern Black Sea	**Varna**	+0.21	-0.21	-1.05

Results

Region	Groups of soil according to TAW					
	Small 116 mm m^{-1}		Medium 136-157 mm m^{-1}		Large 173-180 mm m^{-1}	
	RYD %	NIRs mm	RYD %	NIRs mm	RYD %	NIRs mm
Sandanski						
Intercept ***a***	79.6	312,3	74.1	294.2	62.1	256.6
Slope coefficient ***b***	-15.0	-66,4	-15.7	-66.2	-16.1	-65.8
R^2 (%)	75	70	77	70	78	70
Stara Zagora						
Intercept ***a***	67.0	259.2	61.81	243.3	51.3	211.4
Slope coefficient ***b***	-19.9	-83.2	-20.5	-83.1	-20.5	-83.4
R^2 (%)	80	77	82	78	83	79
Plovdiv						
Intercept ***a***	65.2	244.4	59.4	226.7	47.2	189.9
Slope coefficient ***b***	-24.8	-97.3	-24.7	-96.4	-23.6	-93.8
R^2 (%)	92	89	92	89	91	89
Lom						
Intercept ***a***	57.7	202.5	51.3	184.7	38.5	148.7
Slope coefficient ***b***	-23.8	-81.7	-23.6	-81.5	-22.1	-78.9
R^2 (%)	86	80	86	80	86	81
Sofia						
Intercept ***a***	48.4	178.8	42.6	162.5	31.2	129.2
Slope coefficient ***b***	-21.0	-78.2	-20.5	-77.1	-18.8	-73.3
R^2 (%)	76	76	75	75	73	73
Silistra						
Intercept ***a***	56.1	190.3	49.1	171.7	35.9	135.4
Slope coefficient ***b***	-20.5	-68.5	-20.3	-68.5	-19.3	-67.4
R^2 (%)	86	84	86	85	86	85
Pleven						
Intercept ***a***	53.5	202.4	47.6	184.8	35.7	148.4
Slope coefficient ***b***	-23.3	-88.1	-23	-87.1	-21.6	-84.3
R^2 (%)	82	77	81	76	79	75
Varna						
Intercept ***a***	63.6	212.3	56.9	195	43	158.1
Slope coefficient ***b***	-18.1	-59.6	-17.6	-58.7	-16.5	-56.72
R^2 (%)	82	73	81	74	80	73

Parameters of ***y=a+bx*** relationship between simulated ***RYD (%)***/***NIR*** **(mm)** and High Peak Season ***SPI2 "July-Aug"*** across soil groups and climate regions

Bulgaria, 1951-2004

UNSFA

III. Vulnerability of agriculture to drought

Irrigation requirements, rainfed maize yield and risky years, Rimski Sancevi

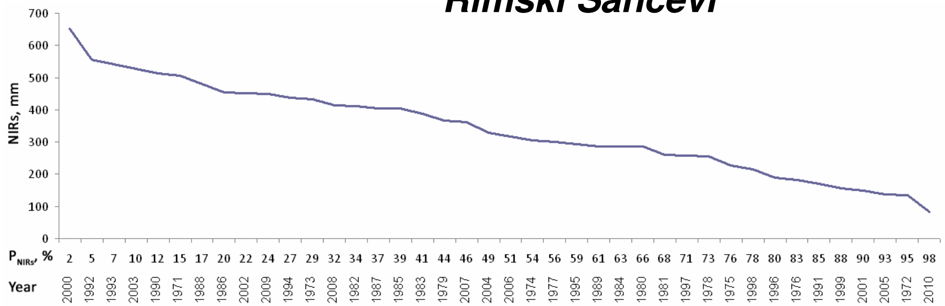


Fig. 23. NIR probability, **TAW = 146 mm·m^{-1}**, 1971-2010

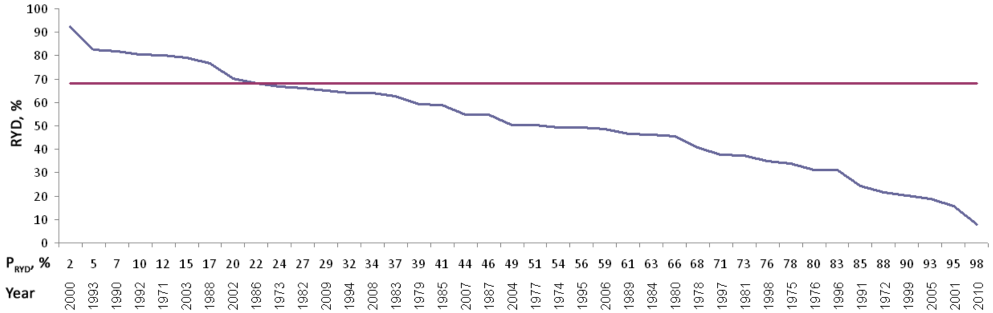


Fig. 24. RYD probability, **TAW = 146 mm·m^{-1}**, EYDT = 68% , 1971-2010

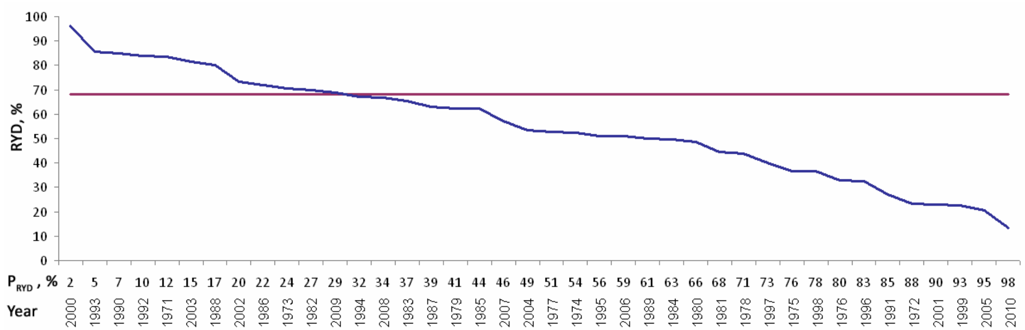


Fig. 28. RYD probability, **TAW = 108 mm·m^{-1}**, EYDT = 68%

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III. Vulnerability of agriculture to drought

Irrigation requirements, rainfed maize yield and risky years, Kikinda

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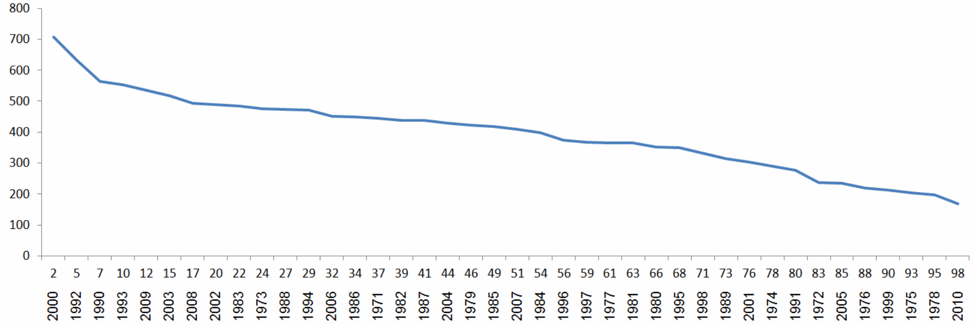

Fig. 31. NIR probability, **TAW = 140 mm·m^{-1}**, 1971-2010

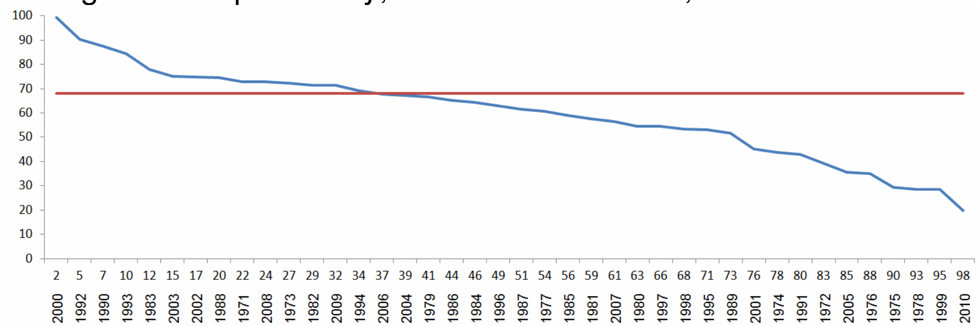

Fig. 32. RYD probability, **TAW = 140 mm·m^{-1}**, EYDT = 68%, 1971-2010

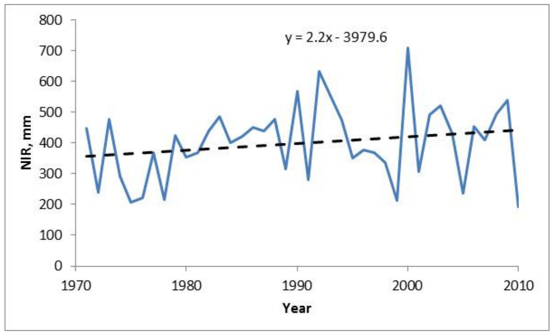

Fig. 37. Net irrigation requirements, **TAW=114 mm·m^{-1}**, 1971-2010

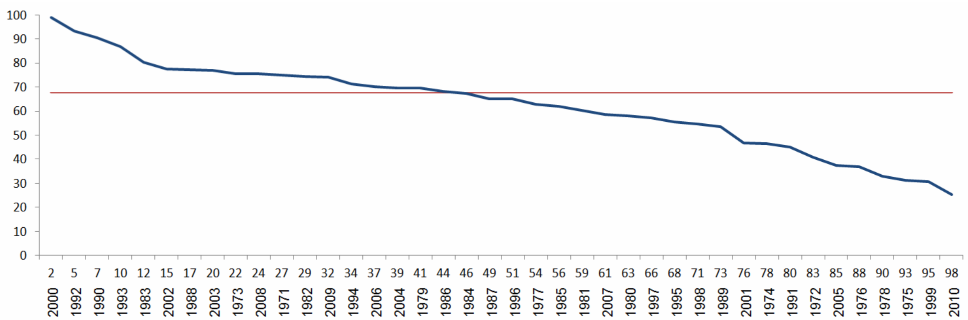

Fig. 36. RYD probability, **TAW = 114 mm·m^{-1}**, EYDT = 68%, 1971-2010

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III. Vulnerability of agriculture to drought

Irrigation requirements, rainfed maize yield and risky years, Nis

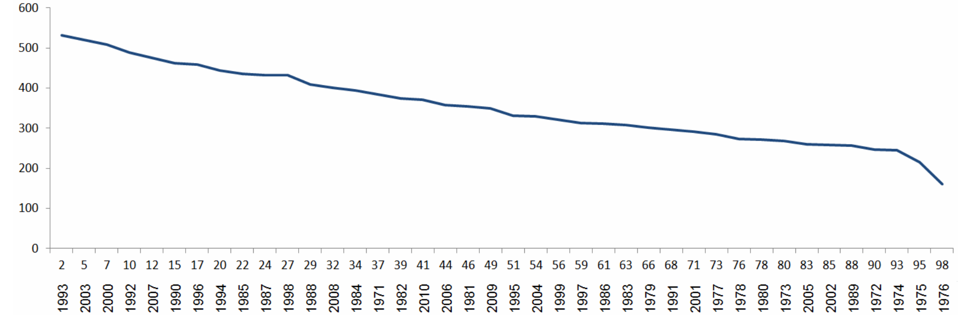


Fig. 43. NIR probability, **TAW = 156 mm·m^{-1}** , 1971-2010

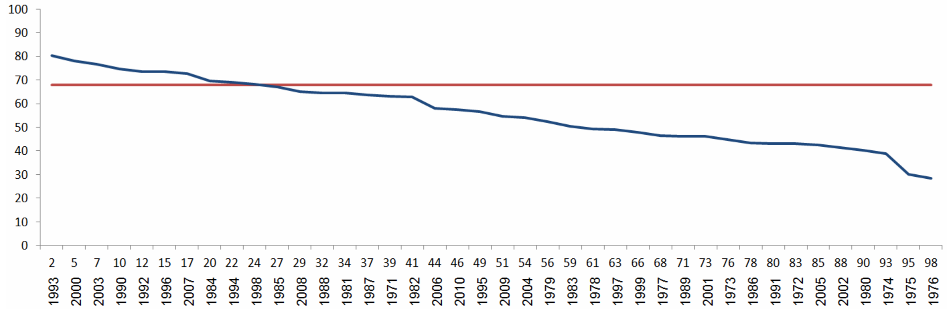


Fig. 44. RYD probability, **TAW = 156 mm·m^{-1}**, EYDT = 68% , 1971-2010

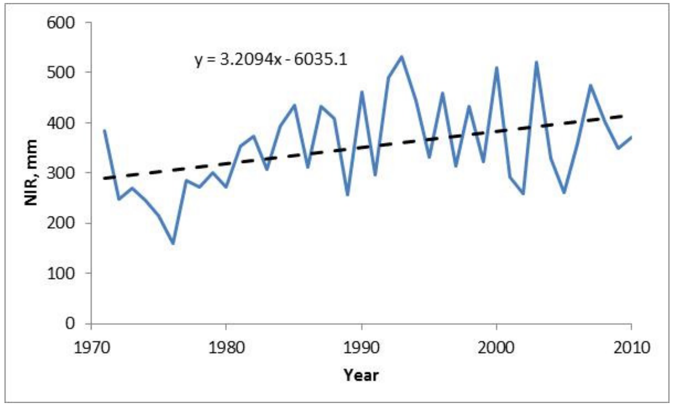
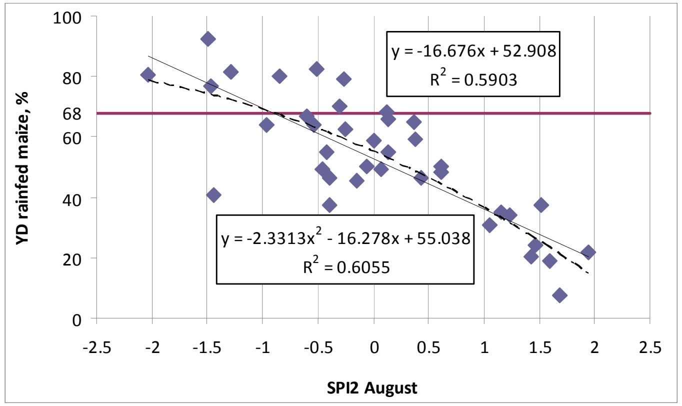


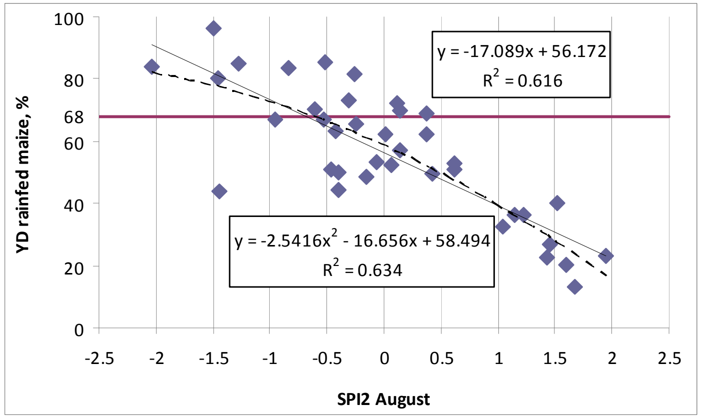
Fig. 45. NIR, **TAW=156 mm·m^{-1}** , 1971-2010

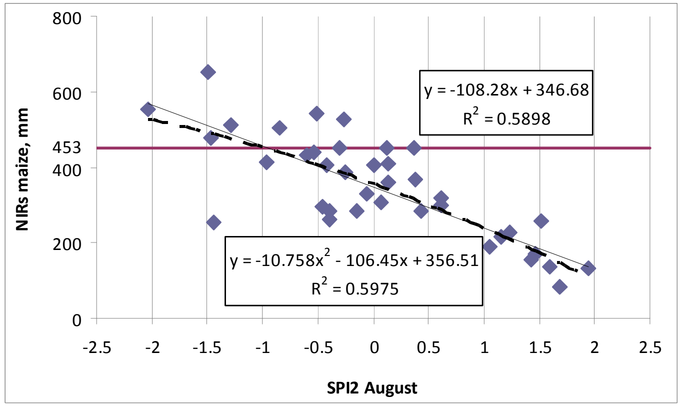
UNSFA

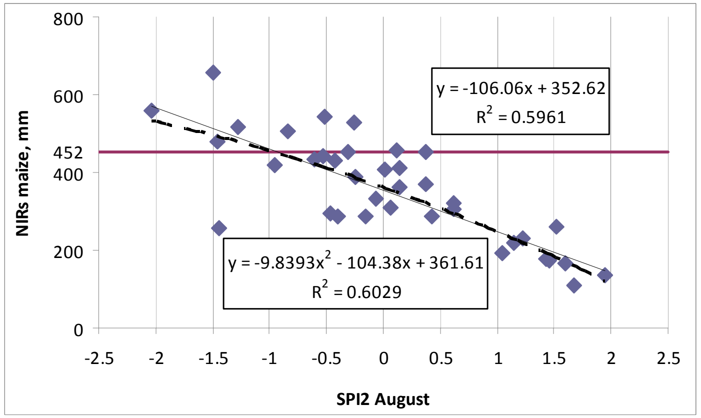
III. Vulnerability of agriculture to drought

Deriving of drought vulnerability categories, Rimski Sancevi









Relationship between High Peak Season "July-August" SPI2 and RYD or NIR, a) A Calcareous Chernozem **TAW=146 mm·m^{-1}**; b) **TAW=108 mm·m^{-1},** 1971-2010

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III. Vulnerability of agriculture to drought

Deriving of drought vulnerability categories, Nis

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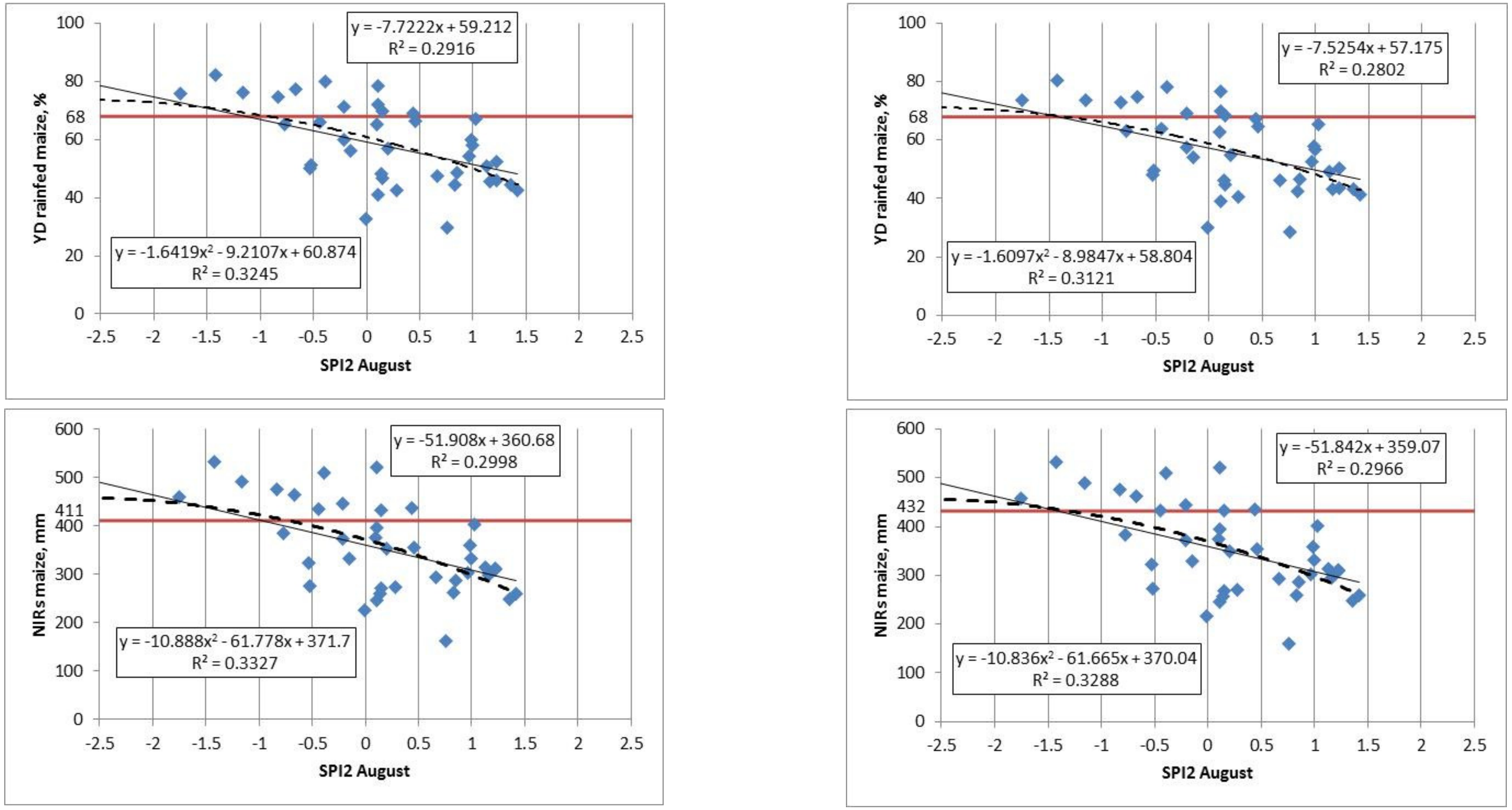

Relationship between High Peak Season "July-August" SPI2 and RYD or NIR, a) A Vertisol **TAW=133 mm·m^{-1}**; b) **TAW=156 mm·m^{-1},** 1971-2010

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HI-M

III. Vulnerability of agriculture to drought

Rainfed maize yield and risky years, Montenegro

Programme co-funded by the EUROPEAN UNION

RYD (%) on soil of small, medium and large TAW, **1980-2009**

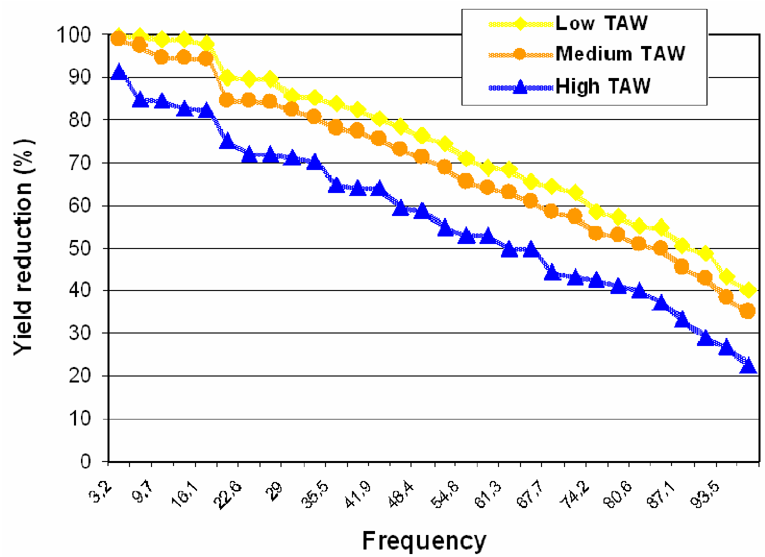

Fig. 14 Early sown maize, Podgorica

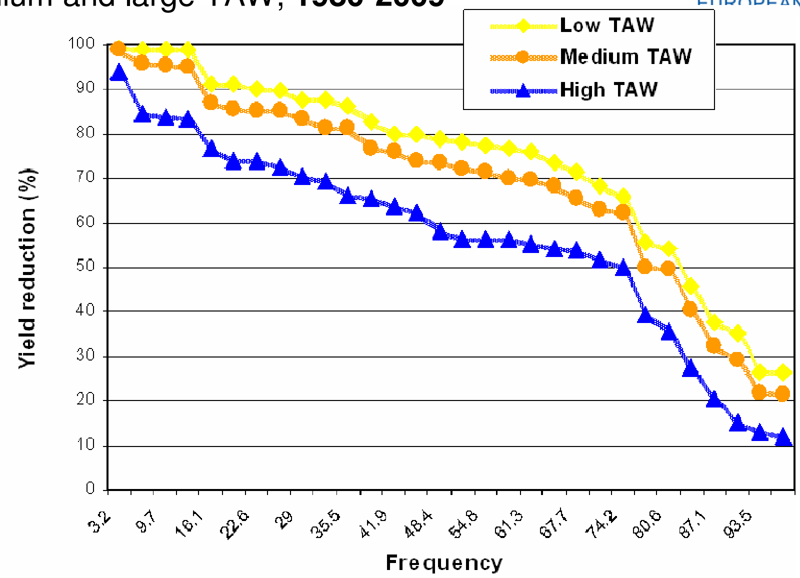

Fig. 26 Maize as a second crop, Podgorica

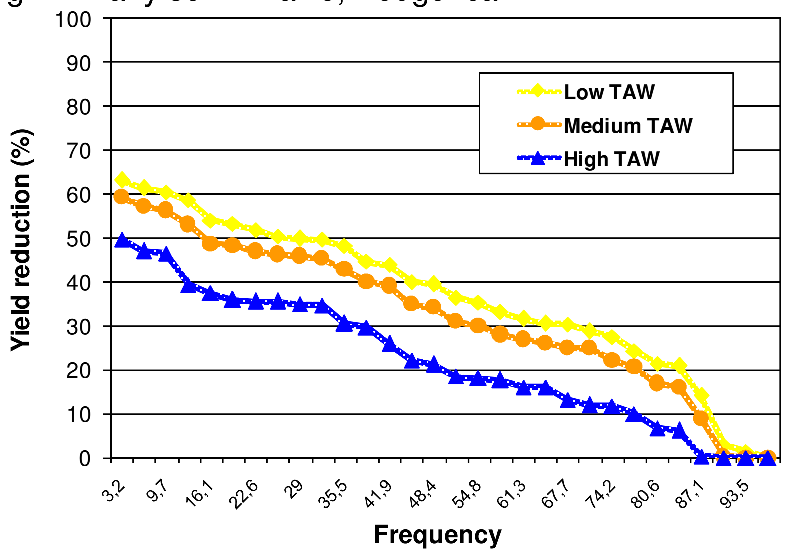

Fig. 38 Early sown maize, Berane

EYDT=40%

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HI-M

III. Vulnerability of agriculture to drought

Net irrigation requirements for maize, Montenegro

NIR (mm) on soil of small, medium and large TAW, **1980-2009**

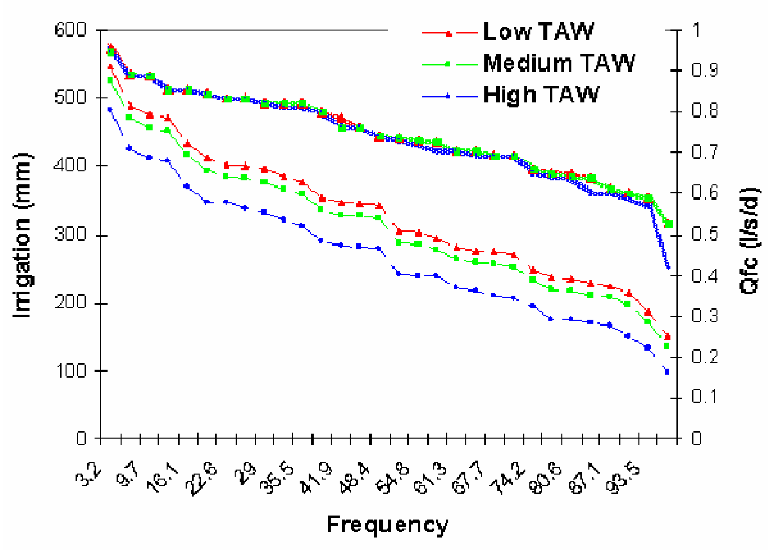

Fig. 15 Early sown maize, Podgorica

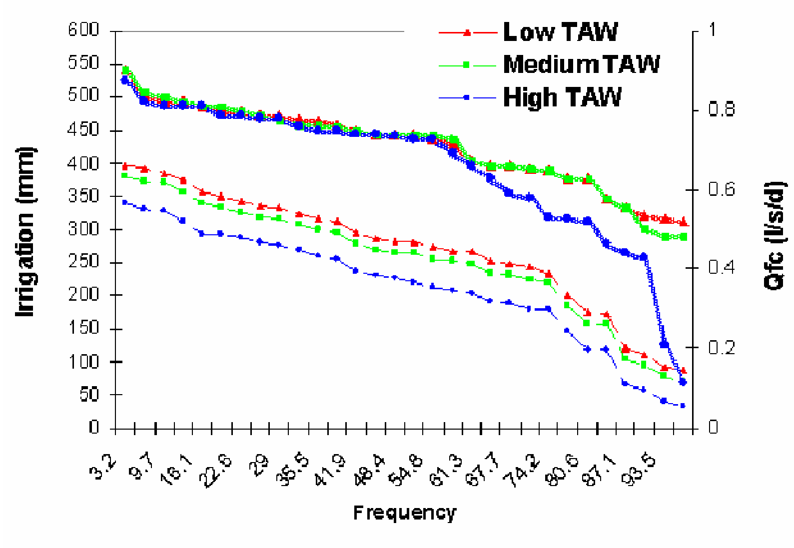

Fig. 27 Maize as a second crop, Podgorica

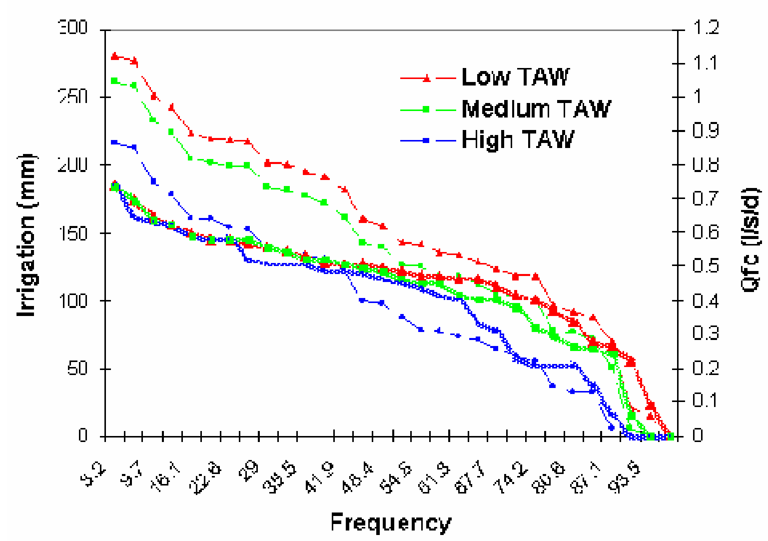

Fig. 39 Early sown maize, Berane

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HI-M – a case study
III. Vulnerability of agriculture to drought

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Deriving of drought vulnerability categories for Montenegro

Podgorica ***Berane***

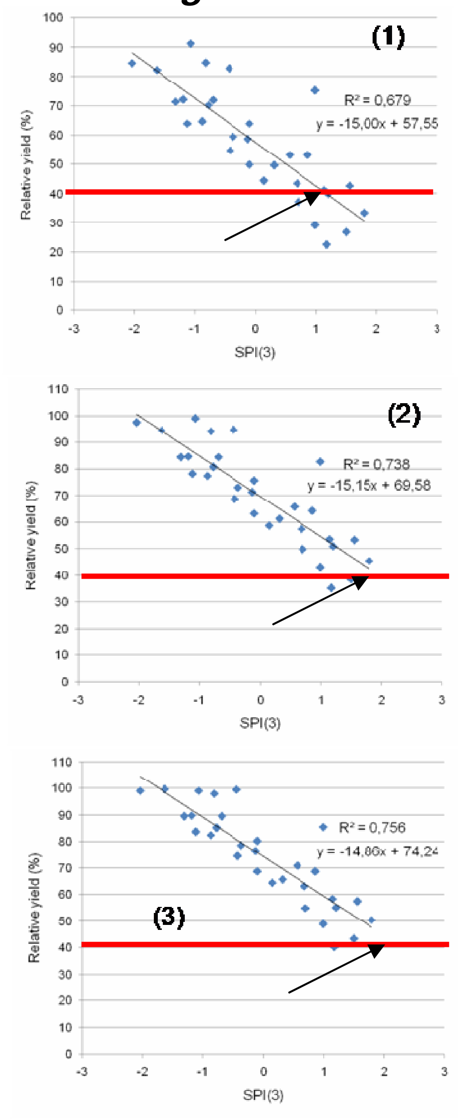


Fig. 16 Relation between SPI (3) “June-Aug” and RYD (%) for April sown maize: soil of large (1), medium (2) and small TAW (3) , **1980-2009**

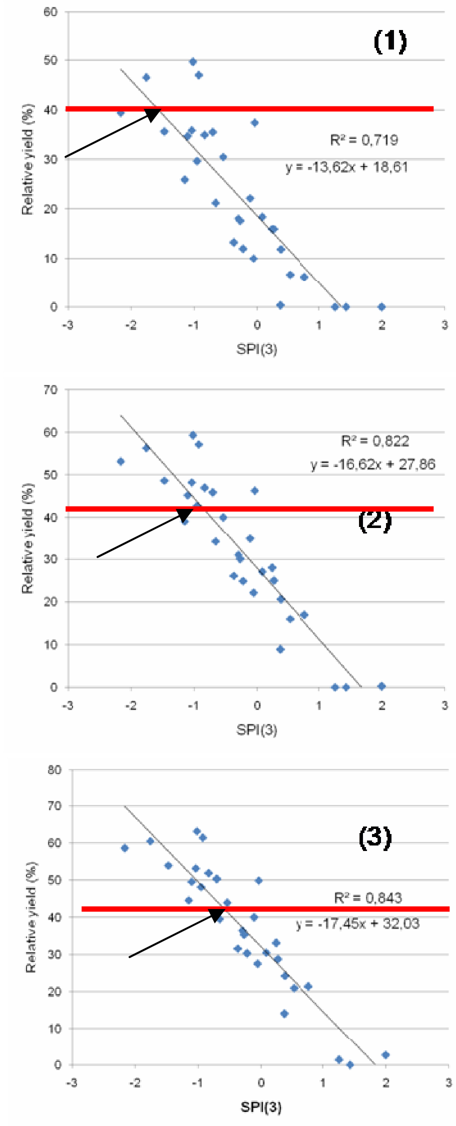


Fig. 40 Relation between SPI (3) “June-Aug” and RYD (%) for maize on soil of large (1), medium (2) and small TAW (3), **1980-2009**

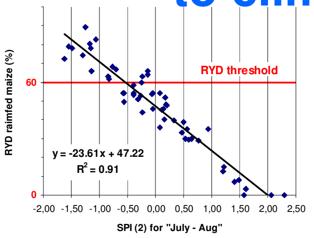
future

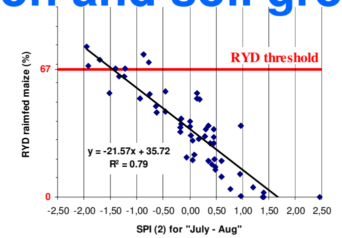
Results

III. Drought vulnerability categories according to climate region and soil group SEE

Plovdiv and

Pleven, TAW=180 mm m^{-1}





Economical threshold of High Peak Season SPI2 "July-Aug" (the average SPI2 for July and August) or SPI3 "June-Aug" indicating the risk relative to rainfed maize for each climate region/soil group in SEE

Climate Region		Soil groups according to total available water *TAW:*		
		Small 116 mm m^{-1}	Medium 136-157 mm m^{-1}	Large 173-180 mm m^{-1}
Mediterranean	**Podgorica***	+2.30	+2.00	+1.20
Transitional Mediterranean	**Sandanski**	+1.40	+1.00	+0.20
Transitional Continental	**Stara Zagora**	+0.50	+0.10	-0.50
	Plovdiv	+0.15	0.00	-0.50
Moderate Continental	**Lom**	+0.15	-0.10	-0.75
	Sofia	0.00	-0.25	-0.90
	Silistra	-0.15	-0.50	-1.25
	Pleven	-0.50	-0.75	-1.50
	Nis		-1.1	-1.4
Typical Continental	**Rimski Sancevi**	-0.70	-1.00	
	Kikinda	-0.40	-0.6	
Mountainous	**Berane***	0	-0.8	-1.5
Northern Black Sea	**Varna**	+0.21	-0.21	-1.05

**High Peak Season SPI3 "June-Aug"*

Results

III. 4C Drought vulnerability mapping, *NIMH*

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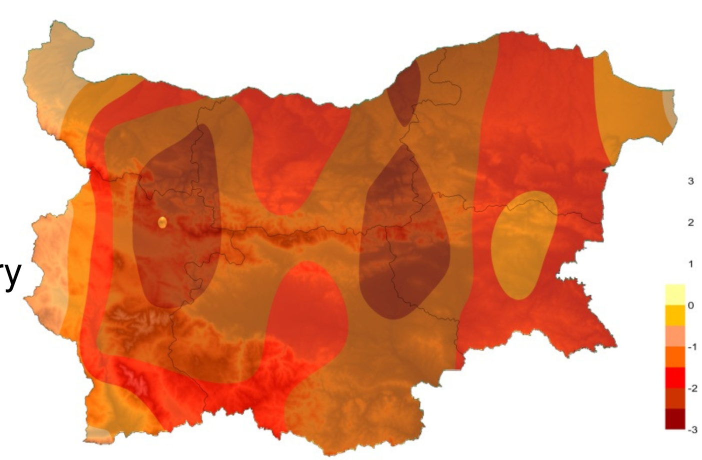
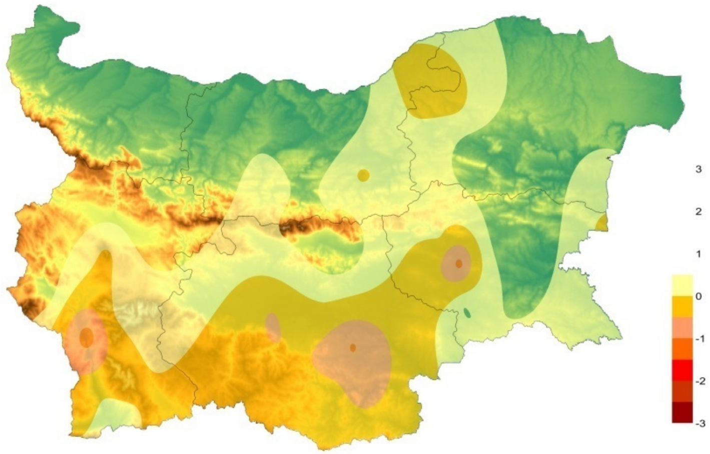
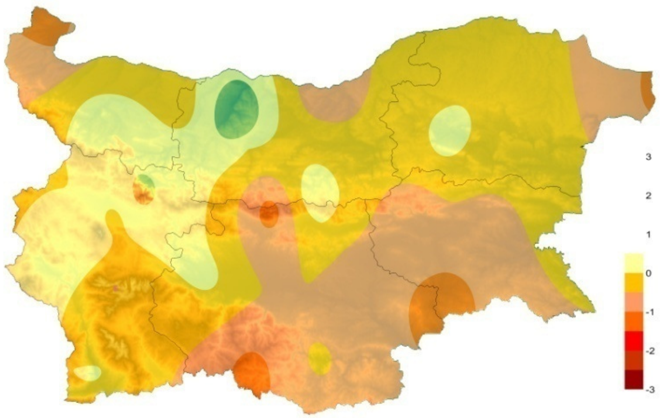
Spatial distribution of seasonal SPI2 “July-Aug”

extremely dry
2000





average
1970

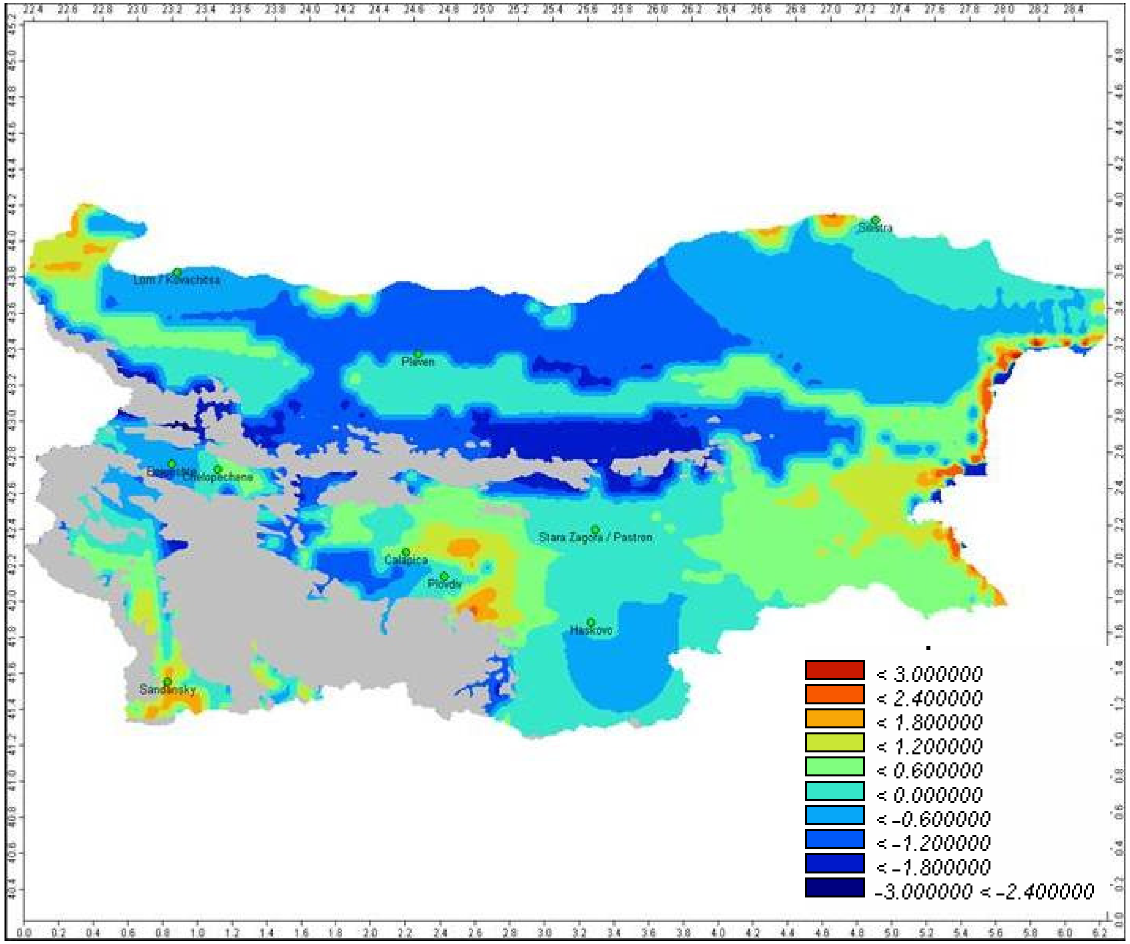


dry 1981

Results

III. 4C Drought vulnerability mapping, *EARS and ISSNP*

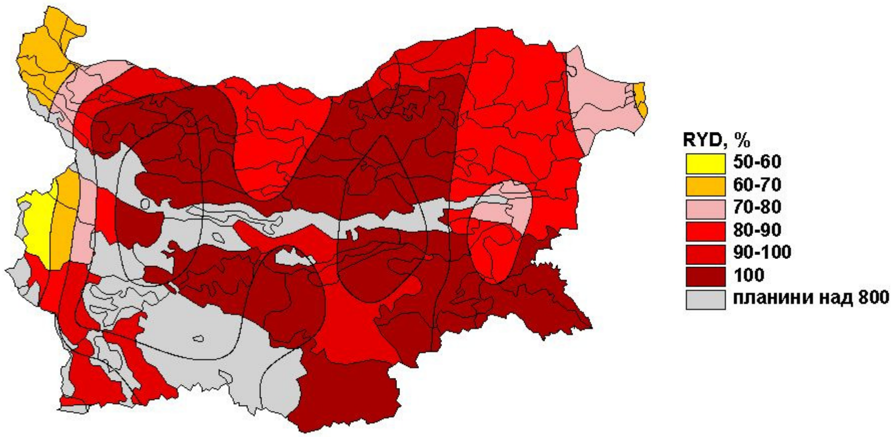
Economical SPI2 “July-Aug” threshold, under which soil moisture deficit leads to severe impacts on yield losses for rainfed maize, Bulgaria.



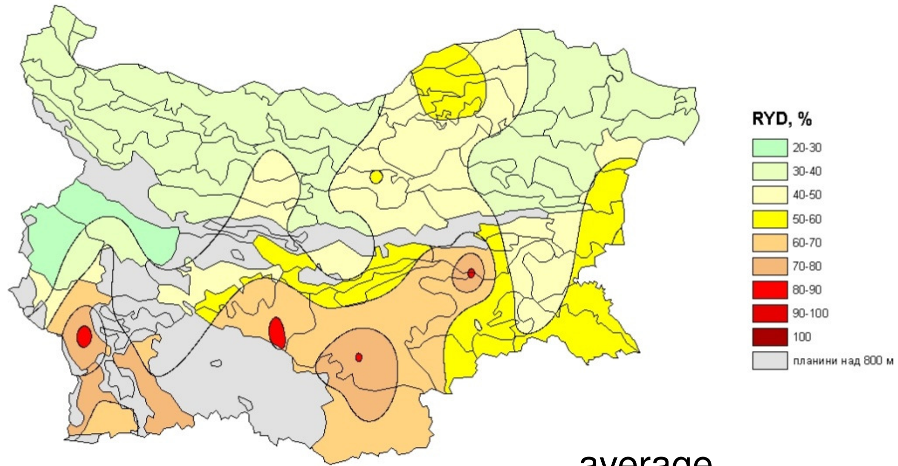
Results

III. 4C Drought vulnerability mapping, *ISSNP and NIMH*

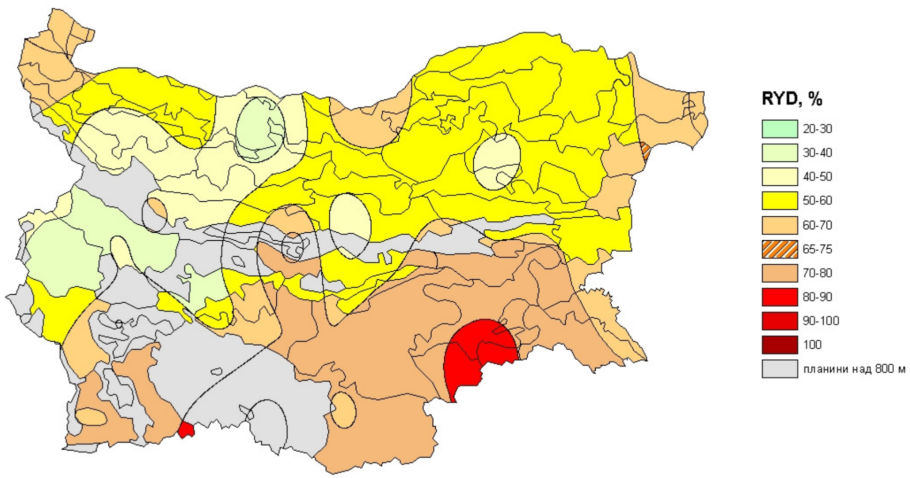
Spatial distribution of relative yield decrease RYD (%)



extremely dry 2000



average 1970



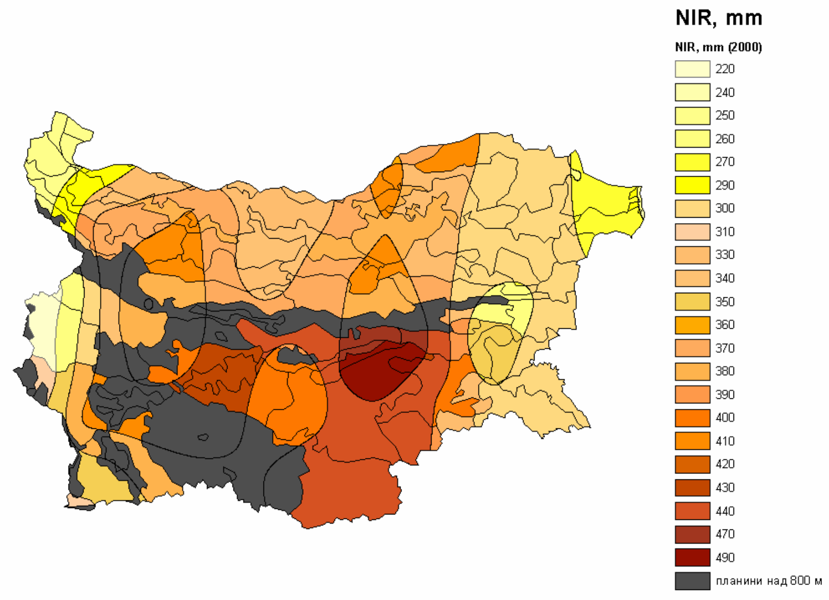
dry 1981

SOUTH EAST EUROPE

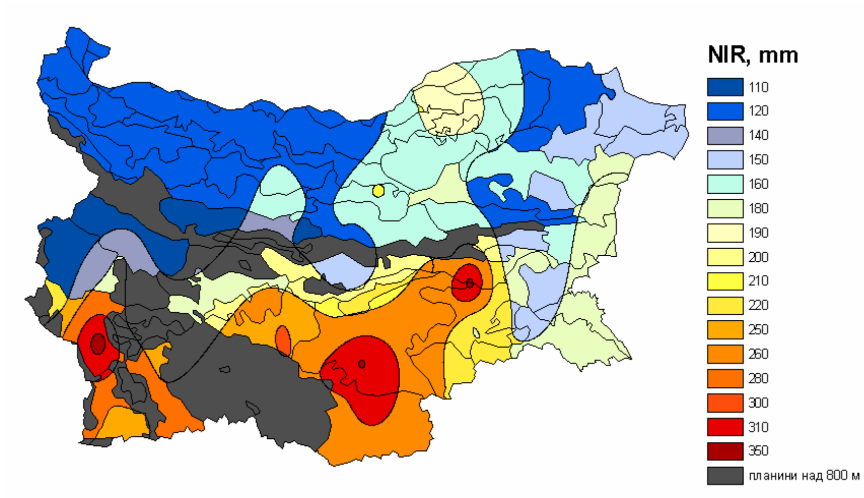
Results

Spatial distribution of net irrigation requirements, NIR, *ISSNP and NIMH*

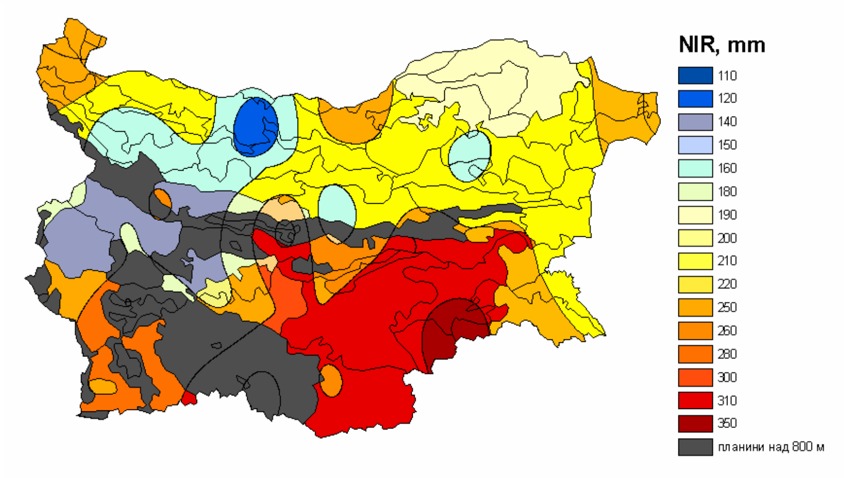
Programme co-funded by the EUROPEAN UNION



extremely dry 2000



average 1970



dry 1981

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Conclusions

- The study relative to eight climate regions, three soil groups and the period 1951-2004 in **Bulgaria** shows that:
- In soils of large *TAW* , **Plovdiv, *NIRs*** range 0-40 mm in wet years and 350-380 mm in dry years. In soils of small *TAW* , *NIRs* reach 440 mm in the very dry year. *NIRs* in **Sofia and Silistra** are about 100 mm smaller than in Plovdiv while in **Sandanski and Northern Greece** they are 30-110 mm larger.
- Rainfed maize is associated with great yield variability (**29%<*Cv*<72%).** The smallest *Cv* refers to Sofia field for soils of large *TAW* (29%) while *Cv*=42% is typical for soils of small *TAW* there. The most variable yields are found in Sandanski (*Cv*=72%) and Plovdiv (*Cv*=69%) if *TAW*=116 mm m-1. The variability of rainfed maize yield in the Danube Plain (30<*Cv*<55%) for Pleven, Varna and Silistra is much lower than in the Thracian Lowland.
- Considering an *ERYD* threshold of 60 and 48% of the potential maize productivity in Plovdiv and Sofia, **30 %** of years are risky when *TAW*=180 mm m-1 in Plovdiv, that is double than in Sofia and half than in Sandanski. In North Bulgaria the *ERYDT* is 67, 55 and 60% for Pleven, Lom and Silistra. When *TAW* is large, only about **10%** of the years are risky in **Pleven and Silistra** that is half than in **Lom**. When *TAW* is medium (157 mm m-1) the risky years rise to **19, 35 and 45 %** in the three sites respectively and reach **50% in Varna**.
- In Plovdiv region reliable relationships (R2>91%) were found for seasonal agricultural drought relating the **SPI2 for "July-Aug"** with the simulated ***RYD* of rainfed maize** while in Stara Zagora, Sandanski and Sofia the relationships were less accurate (73<R2<83%). The study found statistically significant correlations between SPI2 "July-Aug" and simulated *RYD* of rainfed maize for North Bulgaria (R2>0.81) as well.
- When maize is grown without irrigation on soils of **large *TAW*** maize development is less affected by the water stress and economical losses are produced if high peak season SPI2 is less than **+0.20** in Sandanski, **-0.50** in Plovdiv and Stara Zagora and **-0.90** in Sofia field. This threshold ranges between **-0.75** (Lom) and **-1.50** (Pleven) for North Bulgaria. Corresponding NIR thresholds were identified.
- The derived reliable relationships and specific thresholds of seasonal SPI2 "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 South East Europe. They are used for elaboration of drought vulnerability maps and identification of drought prone territories at regional and national level.

SOUTH EAST EUROPE

- The study relative to the period 1971-2010 for **Serbia** shows that:
- -**In Rimski Sancevi,** the soil of TAW = 146 mm·m^{-1} NIRs range from 80-135 mm in wet seasons to **230-390 mm** in average demand seasons and reach 555-650 mm in very dry years; for the soil of TAW = 108 mm·m^{-1} NIR is similar, except for the very wet year (111 mm)
- - Considering an EYDT of 4.7 t·ha^{-1} of dry grain under which maize cultivation is not profitable, it is found that 22% of years are associated with economic losses on rainfed fields when TAW is medium (=146 mm·m^{-1}) and 30% when it is small (108 mm·m^{-1})
- - It is found that when rainfed maize is grown on soils of medium water holding capacity (TAW=146 mm·m^{-1}) economic losses are produced when High Peak Season SPI (2) is less than -1 and when it is less than -0.7 on soils of small water holding capacity (TAW=108 mm·m^{-1})

- The study relative to the same period for **Kikinda** shows that:
- - For the soil of TAW = 140 mm·m^{-1} NIRs range from 170-200 mm in wet seasons to **315-440 mm** in average demand seasons and reach 630-710 mm in very dry years; for the soil of TAW = 114 mm·m^{-1} NIR is similar but for the very wet years (192-206 mm)
- - Considering the same EYDT, it is found that **35%** of years are associated with economic losses on rainfed fields when the soil water holding capacity is medium (TAW=140 mm·m^{-1}) and **45%** when it is small (TAW=114 mm·m^{-1})
- - When rainfed maize is grown on soils of medium TAW (140 mm·m^{-1}) economic losses are produced when High Peak Season SPI (2) is less than **-0.6** and less than **-0.4** on soils of small TAW (114 mm·m^{-1})

- The results relative to **Nis** shows that:
- - For the soil of TAW = 133 mm·m^{-1} NIRs range from 160-225 mm in wet seasons to **290-370 mm** in average once and reach 521-533 mm in very dry years; for the soil of TAW = 156 mm·m^{-1} NIRs is similar
- - Considering the same EYDT, it is found that 28% of years are associated with economic losses on rainfed fields when TAW is medium (133 mm·m^{-1}) and 25% when it is larger (156 mm·m^{-1})
- - For rainfed maize grown on soils of medium TAW (**133 mm·m^{-1}**) economic losses are produced when High Peak Season SPI (2) is **less than -1.1** and less than **-1.4** on soils of larger **TAW (156 mm·m^{-1})**