Effects of precipitation and temperatures on crop yield variability in Vojvodina (Serbia)

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Effects of precipitation and temperatures on crop yield variability in Vojvodina (Serbia)

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Abstract: *The influence of precipitation, mean, maximum and minimum temperatures on maize, sugar beet, soybean and sunflower yields was examined in the Autonomous Province of Vojvodina (Republic of Serbia) for the period 1949-2013. The results showed that growth period precipitation increased by 9 mm decade^{-1} and mean, maximum and minimum temperatures increased by 0.2 °C decade^{-1}. On a monthly basis, significant precipitation increase was in September (3.9 mm decade^{-1}) and highest temperature increase was in August with 0.3 °C decade^{-1} for mean, maximum and minimum temperatures. Maize, sugar beet and sunflower yields were strongly correlated with precipitation and temperature during growth period. Growth period precipitation explained 23%, 14% and 12% of interannual variability of sunflower, maize and sugar beet yield, respectively. On a monthly basis, summer months (July and August) precipitation showed significant positive correlation with all crop yields, except soybean. Temperature variables during March, August and September were most responsive for crop yields.*
Keywords: *agriculture, climate change, crop yield, correlation, Vojvodina, Serbia.*

Riassunto: *L'influenza delle precipitazioni e delle temperature media, massime e minime sui rendimenti di mais, barbabietola da zucchero, soia e girasole è stata esaminata nella Provincia autonoma della Vojvodina (Repubblica di Serbia) per il periodo 1949-2013. I risultati hanno mostrato che nel periodo di crescita le precipitazioni sono aumentate di 9 mm per decade, mentre le temperature medie, massime e minime sono aumentate di 0,2 °C nel decennio. Su base mensile, significativo aumento delle precipitazioni è stato nel mese di settembre (3,9 mm per decade) e il più alto aumento di temperatura è stato nel mese di agosto con 0,3 °C decennio-1 per medie, massime e minime. I rendimenti di mais, barbabietola da zucchero e girasole sono fortemente correlati con precipitazioni e temperatura durante il periodo di crescita. Le precipitazioni nel periodo di crescita spiegano il 23%, 14% e 12% di variabilità interannuale di girasole, mais e resa barbabietola da zucchero, rispettivamente. Su base mensile, nei mesi estivi (luglio e agosto) la precipitazione ha mostrato una significativa correlazione positiva con tutti i raccolti, ad eccezione della soia. Le condizioni di temperatura durante marzo, agosto e settembre sono state più importanti per la resa delle colture.*
Parole chiave: *agricoltura, cambiamenti climatici, resa delle colture, correlazione, Vojvodina, Serbia.*

1. INTRODUCTION

Some of the most profound and direct impacts of climate change over the next few decades will be on agricultural and food systems (Brown and Funk, 2008). Until the middle of the XXI century, the world's population is forecast to increase by 2 billion people. To meet the projected demand, global agricultural production will have to increase by 60 percent from its 2005-2007 levels (FAO, 2013b).

Climatic impacts on agricultural production were investigated on global (Parry *et al.*, 1999; Lobell and Field, 2007), continental (Bindi and Olesen, 2011; Iglesias *et al.*, 2012), national (Cuculeanu *et al.*, 1999; Alexandrov and Hoogenboom, 2000; Lobell and Asner, 2003; Magrin *et al.*, 2005; *Chloupek et al.*, 2007; Meza and Silva, 2009; Harrison *et al.*, 2011; Rowhani *et al.*, 2011; Tao *et al.*, 2014) and regional level (Alexandrov *et al.*, 2002; Bannayan *et al.*, 2011; Cociu, 2012; Licker *et al.*, 2013). Comprehensive investigations of climate-crop relations in Vojvodina are scarce. Lalić *et al.*, (2011) investigated the influence of climate change on winter wheat production in Vojvodina, while Jančić(2013) investigated climatic impacts on maize production in a small part of Vojvodina.

Thanks to favorable agro-ecological conditions, agriculture has been traditionally one of the most important sectors of the Serbian economy. Due to this, factors affecting agriculture also influence the economy of the whole country (Lalić *et al.*, 2011). In 2010, Serbia was the largest producer of coarse grains (7,660,000 t), sugar beet (3,325,000 t) and oil-bearing crops (262,000 t) in South Eastern Europe (FAO, 2013a). This represents 0.7%, 0.2% and 1.5% of coarse grains, oil-bearing crops and sugar beet world's production, respectively (FAO, 2013b).

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Autonomous Province of Vojvodina is located in southeastern part of Pannonian Plain and represents the northern part of the Republic of Serbia (Fig. 1). It has a surface area of about 21,500 km^2 with population of two million. Vojvodina is country's most important agricultural area with 61.5%, 87.6%, 64.9% and 88.3% of country's maize, sugar beet, soybean and sunflower production, respectively during 1949-2013 period.
Climate of Vojvodina is moderate continental with cold winters and hot, humid summers. Annual precipitation in Vojvodina is 598 mm during 1949-2013 period. It is characterized by continental precipitation regime with highest rainfall quantities in summer when around 33% of precipitation totals occur (196 mm). In the investigated period, annual mean, maximum and minimum air temperature values were 11.2 °C, 16.5 °C and 6.1 °C, respectively.
Effects of climate change on agriculture are particularly significant in undeveloped and developing countries (such as Serbia), due to difficult economic situation and low investments in production improvement (Lalić *et al.*, 2011). Climate forecasting is filled with uncertainties and Serbia is no exception. Due to the lack of regional agrometeorological service, farmers in Vojvodina do not have the opportunity to employ climate information for agricultural planning and decision-making. The Republic Hydrometeorological Service of Serbia provides agrometeorological information for the territory of Vojvodina. Unfortunately, majority of information are given for the previous agrometeorological period (e.g. weekly, monthly and annual agrometeorological bulletins) and only potential evaporation data is provided for the future nine days. Furthermore, farmers do not have in advance the information about prices of crops. As a consequence, annual yield variability exposes farmers to a lot of pressure regarding seasonal income and food security.
Precipitation and temperature variability during growth period are especially important for crop cultivation. Except them, non-climatic influences such as improvements in crop genetics and technical factors are also very important for crop development and yield.
For a future climate change condition (2071-2100) assuming the A1B emission scenario of the

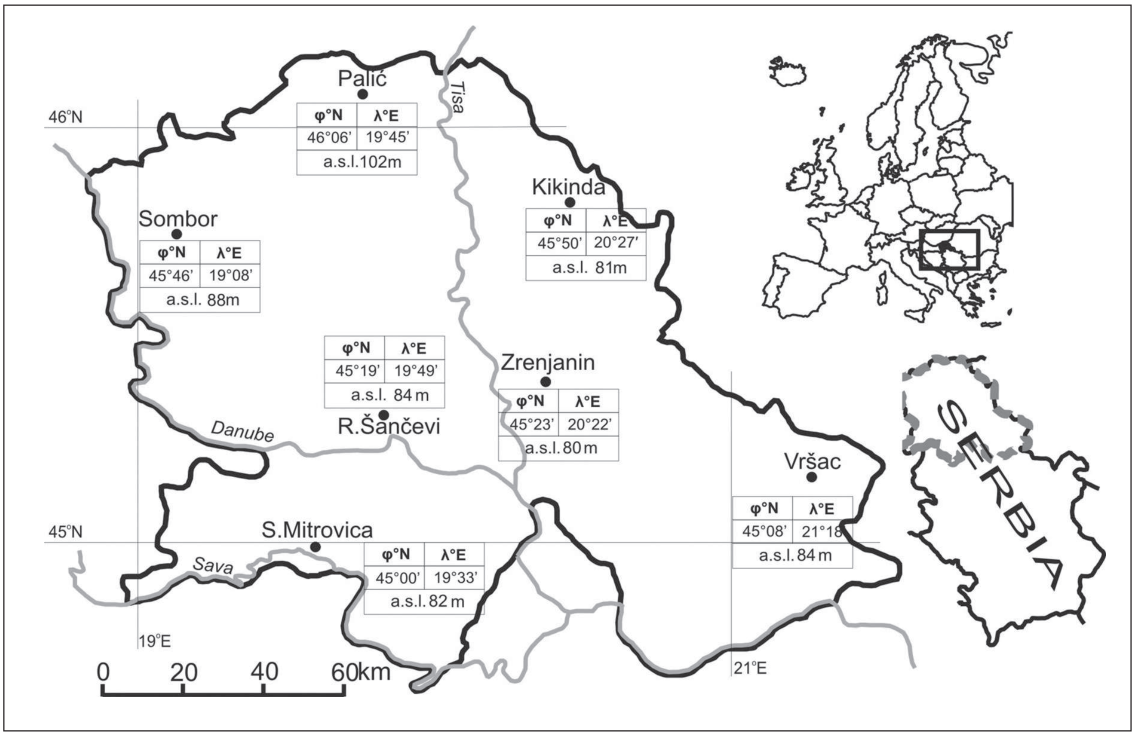

Fig. 1 - Geographical locations, coordinates and elevation (m) of the main meteorological stations in Vojvodina (North Serbia).
Fig. 1 - Localizzazione geografica, coordinate e quota (m) delle principali stazioni meteorologiche in Vojvodina (Serbia settentrionale).

Intergovernmental Panel on Climate Change (IPCC, *http://www.ipcc.ch/*), where fossil intensive and non-fossil energy sources are balanced and there is not a heavy dependence on one particular energy source and a similar improvement rate is applied to all energy supply and end-use technologies, a high risk of yield damage for key crops (wheat, maize, rice and soybean) was found for continental lands at high latitudes, particularly in the Northern Hemisphere between 40°N and 60°N (Teixeira *et al.,* 2013) where Vojvodina is located. Before the investigation of the future climate-crop relations it is necessary to address its historical relations. Our objectives in this study are to understand (1) how climate has changed during growth period in Vojvodina in the past 65 years? (2) how harvested area, production and yields of four major spring sown crops has changed in the 1949-2013 period? and (3) to what extent precipitation and temperatures variability has affected yields variability of investigated crops in the research period?

2. MATERIALS AND METHODS

Historical monthly weather data, including total precipitation (P), mean air temperature (T_{mean}), maximum air temperature (T_{max}) and minimum air temperature (T_{min}) were acquired from the Meteorological yearbooks of the Republic Hydrometeorological Service of Serbia. We selected seven main meteorological stations in Vojvodina that had good records of weather variables from 1949 to 2013 (Fig. 1). Serbian Meteorological Service and authors realized quality control of the meteorological data. The mean monthly and growth period (GP) (March-October) P, T_{mean}, T_{max} and T_{min} time series for Vojvodina have been calculated from of seven monitoring stations in order to relate the climate data to the agricultural production in the region. This is acceptable because stations are relatively equally distributed in the investigated region with one station for every 3000 km^2 and they are located on similar elevation (from 80 m a.s.l. to 102 m a.s.l.) (Fig. 1).

Crop cultivation statistics (harvested area, production and yield) of maize (Zea mays L.), sugar beet (Beta *vulgaris* L.), soybean (*Glycine max* L.) and sunflower (*Helianthus annuus* L.) were acquired from the Statistical Office of the Republic of Serbia from 1949 to 2013. These are important spring crops for agricultural production in Vojvodina that provide seasonal income and employment for a large number of the regional rural population. Sowing of studied crops happens in spring (March-April) while harvesting is in autumn months (September-October).

Time trends in P, T_{mean}, T_{max} and T_{min} on a monthly basis and for the whole GP and time trends in crop cultivation characteristics for whole GP were analyzed using linear regression method. Mann-Kendall non parametric statistical test (Sneyers, 1991) was used for detecting the statistical significance of climate trends. For calculation MAKESENS software package was used developed by Finnish Meteorological Institute. Statistical significance was defined on the 0.001, 0.01, 0.05 and 0.1 level of significance (Salmi *et al.,* 2002). This test is widely used in environmental science because it is simple, robust and can cope with missing values and values below a detection limit (Libiseller, 2002).

To investigate the correlations between climate variables and crop yields on a monthly basis during GP and for whole GP, the yields were linearly de-trended to get the de-trended yield series mainly affected only by seasonal climate variability. According to the investigated correlation between climate variables anomalies and de-trended yields, influences of non-climatic factors such as improvements in crop genetics and technical factors are omitted. Furthermore, climatic influences are better detected. Then the anomalies of climate variables from averaged values for the whole investigated period 1949-2013 were correlated with the de-trended crop yields using Pearson's correlation in order to investigate their relationship. Correlation was also investigated by the Spearman non-parametric test and similar results (not shown in the paper) were acquired. The Pearson correlation coefficient and its results were used because it provides a significant insight into the similarities between different data sets used in this paper and enables the representation of homogeneous geographical areas such as Vojvodina. Statistical significance was tested using the two-tailed t-test.

3. RESULTS AND DISCUSSION

3.1. Climate trends during growth period from 1949 to 2013

From 1949 to 2013, climate has changed significantly during crops GP in Vojvodina. Precipitation increased in all months during GP (except for April) (Tab. 1) and for whole GP (8.96 mm decade^{-1}) (Fig. 2). Significant precipitation increase was during September with 3.88 mm decade^{-1}. T_{mean} increased significantly in all months, except September and October, and for whole GP (0.20 °C decade^{-1}) (Fig. 2). In all months from April to August and for whole GP (Fig. 2), T_{max} increased significantly (from 0.21 °C decade^{-1} for

Month	P (mm)	P (mm decade-1)		T_{mean} (°C)	T_{mean} (°C decade-1)		T_{max} (°C)	T_{max} (°C decade-1)		T_{min} (°C)	T_{min}(°C decade-1)	
	Average	Trend	R^2	Average	Trend	R^2	Average	Trend	R^2	Average	Trend	R^2
March	35,27	1,11	0,01	5,98	**0.31$^+$**	**0,07**	11,44	**0,39**	**0,06**	1,11	**0.30***	**0,08**
April	47,28	-0,45	0,00	11,65	**0.18$^+$**	**0,04**	17,33	**0.24$^+$**	**0,05**	5,79	**0.20$^+$**	**0,07**
May	59,85	0,25	0,00	16,79	**0.26****	**0,09**	22,47	**0.32***	**0,09**	10,74	**0.26*****	**0,17**
June	80,22	0,71	0,00	19,99	**0.22***	**0,09**	25,85	**0.22$^+$**	**0,06**	13,78	**0.23****	**0,14**
July	63,22	0,42	0,00	21,65	**0.24****	**0,11**	27,92	**0.26****	**0,10**	15,14	**0.24****	**0,13**
August	52,61	0,18	0,00	21,17	**0.28****	**0,11**	27,59	**0.32***	**0,08**	14,74	**0.32*****	**0,24**
September	44,97	**3.88***	**0,07**	16,88	-0,01	0,00	23,66	-0,01	0,01	11,06	0,14	0,04
October	42,04	2,87	0,03	11,47	0,13	0,02	17,72	0,05	0,00	6,42	**0.22***	**0,06**
Growth period (March-October)	425,45	8,96	0,03	15,70	**0.20*****	**0,21**	21,75	**0.21****	**0,15**	9,85	**0.24*****	**0,38**

Tab. 1 - Average values and trends of P (mm), T_{mean}, T_{max} and T_{min} (°C) in Vojvodina on a monthly basis during GP and for whole GP from 1949 to 2013.
$^+$ - level of significance α = 0.1;
* - level of significance α = 0.05
** - level of significance α = 0.01
*** - level of significance α = 0.001
Tab. 1 - Valori medi e le tendenze di P (mm), Tmean, Tmax e Tmin (° C) in Vojvodina su base mensile durante GP e per intero GP 1949-2013.
$^+$ - *livello di significatività α = 0.1;*
* - *livello di significatività α = 0.05*
** - *livello di significatività α = 0.01*
*** - *livello di significatività α = 0.001*

whole GP to 0.32 °C decade^{-1} in August). T_{min} increased significantly in all months, except September, and for whole GP (0.24 °C decade^{-1}) (Fig. 2). Similar trends were obtained for the Republic of Slovenia (Milošević *et al.*, 2013).
Vojvodina's climate exhibited fluctuations during the investigated period, but many of the recent changes were unprecedented. The variation of T_{mean}, T_{max} and T_{min} during GP reveals the succession of cold and warm periods in the past 65 years. The main features include the cold period since ~1960 until ~1980, followed by a phase of mean temperature rise until the end of the investigated period. Similar results were obtained for T_{max} and T_{min} on annual level for Vojvodina in 1949-2008 period (Savić *et al.*, 2014) (Fig. 2b-d). Vojvodina's recent P fluctuations for GP were more evident since ~2000 when it have reached historically low and high levels, respectively (Fig. 2a). Similar results were obtained in Picardy Region (France) and Rostov Oblast (Russia) (Licker *et al.*, 2013).

3.2. Crop cultivation from 1949 to 2013

Of four crops used in this study, maize is by far the most planted crop in Vojvodina with average 645,618 ha year^{-1} in the investigated period. It is followed by sunflower (118,776 ha year^{-1}), sugar beet (59,527 ha year^{-1}) and soybean (48,176 ha year^{-1}) (Tab. 2). Maize and sugar beet harvested areas had

Crop	Statistics	Average	Min	Max	Range	St. Dev.	CoV (%)	Trend value	Trend unit
Maize	H. area (ha)	645.618	514.557	759.296	244.739	53.484	8	1598,7	ha year^{-1}
	Production (Mt)	2,96	0,03	5,15	5,12	1,07	36	0,04	Mt year^{-1}
	Yield (t/ha)	4,52	0,80	6,99	6,19	1,50	33	0,05	t ha year-1
Sugar beet	H. area (ha)	59.527	35.877	99.002	63.125	17.963	30	333,74	ha year^{-1}
	Production (Mt)	2,24	0,29	4,32	4,03	1,10	49	0,03	Mt year^{-1}
	Yield (t/ha)	35,95	6,90	50,96	44,07	10,44	29	0,37	t ha year^{-1}
Soybean	H. area (ha)	48.196	41	158.261	158.220	51.688	107	2483,5	ha year^{-1}
	Production (Mt)	0,11	0,00	0,51	0,51	0,13	119	0,01	Mt year^{-1}
	Yield (t/ha)	1,74	0,31	3,21	2,89	0,68	39	0,03	t ha year-1
Sunflower	H. area (ha)	118.776	31.118	194.968	163.850	49.610	42	1943,1	ha year^{-1}
	Production (Mt)	0,23	0,03	0,48	0,45	0,12	52	0,00	Mt year^{-1}
	Yield (t/ha)	1,85	0,62	2,79	2,17	0,46	25	0,02	t ha year^{-1}

Tab. 2 - Statistics of crops harvested area (ha), production (Mt) and yields (t ha^{-1}) with trends for crops harvested area (ha year^{-1}), production (Mt year^{-1}) and yields (t ha^{-1} year^{-1}) in Vojvodina from 1949 to 2013.
Tab. 2 - Statistiche delle superfici (ha), produzione (Mt) e rendimenti (t ha^{-1}) con le tendenze per la superficie coltivata (ha^{-1} anno), la produzione (Mt anno^{-1}) e rendimenti (t ha^{-1} Yearbook 1) in Vojvodina 1949-2013.

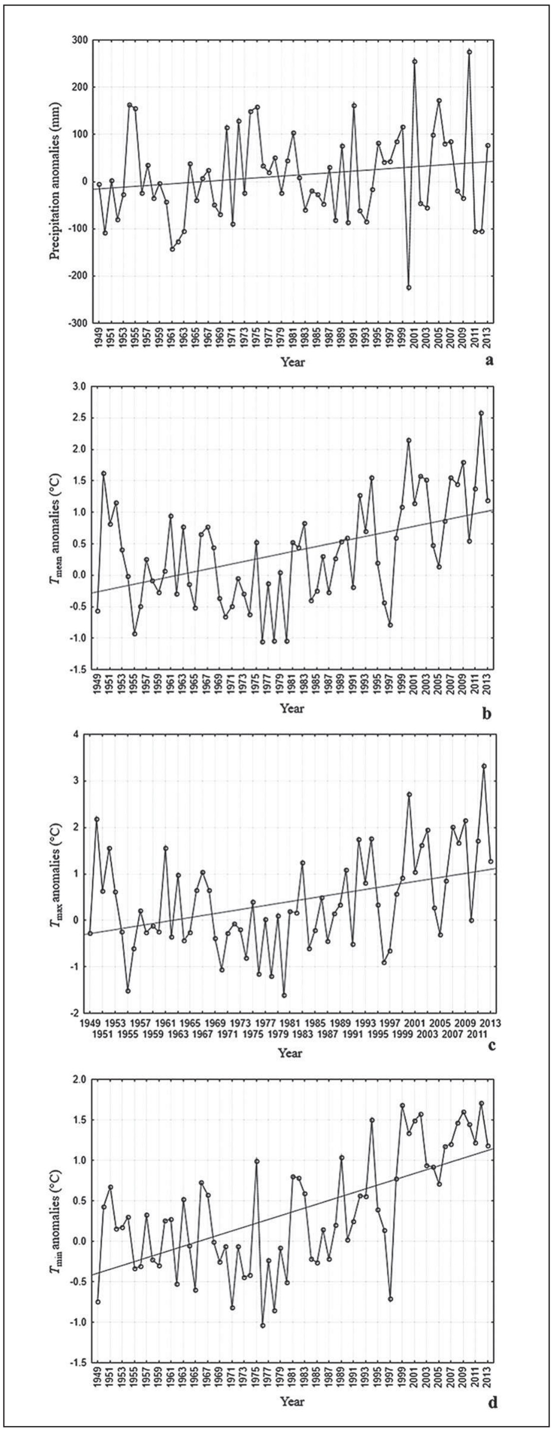

Fig. 2 - Time series of P (mm) (a), T_{mean} (b), T_{max} (c) and T_{min} (d) (°C) anomalies in Vojvodina from 1949 to 2013 (relative to the 1961-1990 baseline period) for the whole GP.
Fig. 2 - Serie temporali delle anomalie di P (mm) (a), Tmean (b), Tmax (c) e Tmin (d) (° C) nella Vojvodina 1949-2013 (rispetto al periodo 1961-1990 di riferimento) per l'intero GP.

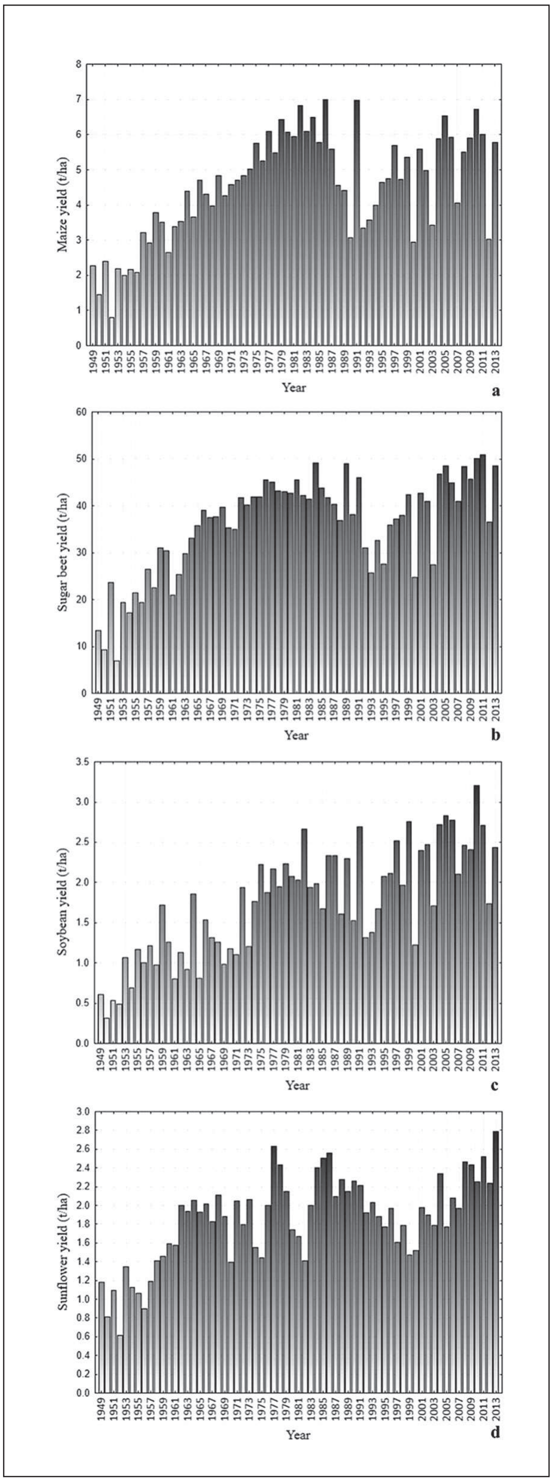

Fig. 3 - Maize (a), sugar beet (b), soybean (c) and sunflower yields (d) (t ha^{-1}) in Vojvodina from 1949 to 2013 period.
Fig. 3 - Rendimenti di mais (a), barbabietola da zucchero (b), soia (c) e girasole (d) (t ha-1) in Vojvodina 1949-2013.

a spike in the 1980-1990 period. After this, maize harvested area declined until the beginning of XXI century when it rose again, while sugar beet harvested area continued to decline until the end of the investigated period. Soybean harvested areas were relatively small (<30,000 ha) until 1980 when it more than tripled in five years reaching maximum value of 158,220 ha in 2010. Sunflower harvested areas generally rose in the earlier part of the investigated period with a spike in 1979. After it started to decline until 1983, but rose again.
Maize and sugar beet production averaged 2.96 Mt year^{-1} and 2.24 Mt year^{-1}, respectively. Sunflower and soybean production was smaller with 0.23 Mt year^{-1} and 0.11 Mt year^{-1}, respectively (Tab. 2). Maize production had a spike in 1986 with 5.15 Mt, after it started to decline. Highest production of sugar beet was during 1980-1990 period with spike in production in 1984 with 4.32 Mt. Soybean production was very small (<0.10 Mt) until 1982, after it increased with a spike in production in 2010 with 0.51 Mt. Sunflower production increased until the 1978, after it declined for a few years and started to rise again with a spike in production in 2013 with 0.48 Mt.
Average yields in the investigated period were 4.52 t ha year^{-1} for maize, 35.95 t ha year^{-1} for sugar beet, 1.85 t ha year^{-1} for sunflower and 1.74 t ha year^{-1} for soybean (Tab. 2). All crops had minimum yields at the beginning of the investigated period reaching maximum yields in the last few years of the investigated period, except for maize (maximum yield was in 1986 with 6.99 t ha^{-1}). Soybean had a spike in yields in 2010 (3.21 t ha^{-1}), sugar beet in 2011 (50.96 t ha^{-1}) and sunflower in 2013 (2.79 t ha^{-1}) (Fig. 3a-d). In comparison, the maximum sugar beet yield that can theoretically be achieved in Germany and comparable agro-climatic regions was calculated as 24 t ha^{-1} (Kenter *et al.*, 2006) that is less than half compared to Vojvodina.
All crops yields increased until the end of 1970s, than starting to decline for a few years and then increased again (Fig. 3). This is in accordance with the period of temperature rise for whole GP and on annual level in Vojvodina (Savić *et al.*, 2014) from the 1980s until the end of the investigated period. The annual variability of yield (as measured by the coefficient of variation - CoV) was 39% for soybean, 33% for maize, 29% for sugar beet, and 25% for sunflower (Tab. 2). This is unfavorable for normal functioning of food industry in Vojvodina due to the potential lack of raw materials in some years.
In general, soybean and sunflower harvested areas increased significantly, followed by maize and sugar beet. Maize and sugar beet had largest production increase followed by soybean and sunflower. Trends of all investigated crop yields were positive with highest value for sugar beet (3.66 t ha decade^{-1}), followed by maize (0.47 t ha decade^{-1}), soybean (0.29 t ha decade^{-1}) and sunflower (0.16 t ha decade^{-1}).

3.3. Correlation between crop yields and meteorological values

3.3.1. Precipitation and crop yields
All crop yields, except soybean, were positively correlated (P<0.01) with precipitation during GP (Tab. 3). This single variable was able to explain approximately 23%, 14% and 12% (R^2) of inter-annual variability of sunflower, maize and sugar beet yield, respectively. Time series of GP precipitation anomalies and de-trended crop yields indicate that often higher than average yields of sunflower (Fig. 4), maize and sugar beet coincide with above average precipitation years while below average yields were obtained in years with below average precipitation. Similarly, in a study of Montemurro *et al.*, (2007) in the year characterized by the lowest total rain in spring and summer (155.8 mm in 1997), the oil production decreased (1.13 t ha^{-1} in 1997) of the 33.9% compared to the year with more precipitation (254.4 mm in 1999) and the highest oil yield (1.71 t ha^{-1} in 1999) at Foggia (Southern Italy). On a monthly basis, precipitation in July showed a significant positive correlation with sunflower (P<0.01) and maize yields (P<0.05). In August, significant positive correlation (P<0.05) was obtained for precipitation and yields of sunflower, maize and sugar beet. In other months, precipitation did not show significant correlation (P>0.05) with crop yields (Tab. 3). This is a very good indicator of summer month's precipitation importance for plant development and yield size.
Other researchers obtained similar results in their studies. Growing season precipitation, minimum and maximum temperatures explained 52% and 47% of the variance in year-to-year yield changes of soybean and maize on a global level, respectively (Lobell and Field, 2007). Precipitation deficit was one of the most important factors that limit growth, development and final yield of maize in Bulgaria (Alexandrov and Hoogenboom, 2000). Higher precipitation during the growing period (April to September) enhanced yields of sugar beet in Czech Republic (Chloupek *et al.*, 2007), while increase in taproot dry matter of sugar beet in Germany during July and August depended on the amount of available water in the soil, while the water input by rainfall and irrigation nor the climatic water balance

Month	Parameter	Maize		Sugar beet		Soybean		Sunflower	
		r	*P*-value	r	*P*-value	r	*P*-value	r	*P*-value
March	Precipitation (mm)	0,18	0,16	0,16	0,21	0,18	0,14	0,13	0,31
	Tmean (°C)	0,20	0,10	**0.33(**)**	**0,01**	0,15	0,25	**0.27(*)**	**0,03**
	Tmax (°C)	0,14	0,26	**0.26(*)**	**0,04**	0,10	0,45	0,23	0,06
	Tmin (°C)	**0.31(*)**	**0,01**	**0.41(**)**	**0,00**	0,23	0,06	**0.32(**)**	**0,01**
April	Precipitation (mm)	0,13	0,31	0,08	0,53	-0,02	0,88	0,13	0,30
	Tmean (°C)	-0,15	0,22	-0,07	0,60	0,16	0,22	-0,02	0,86
	Tmax (°C)	-0,15	0,25	-0,07	0,57	0,15	0,25	-0,02	0,88
	Tmin (°C)	-0,07	0,60	0,04	0,75	0,20	0,12	0,08	0,52
May	Precipitation (mm)	0,12	0,36	0,11	0,37	-0,02	0,87	0,17	0,19
	Tmean (°C)	0,01	0,97	0,01	0,94	0,14	0,26	0,02	0,87
	Tmax (°C)	-0,03	0,84	-0,02	0,89	0,12	0,34	0,00	0,98
	Tmin (°C)	0,15	0,24	0,15	0,25	0,20	0,11	0,17	0,19
June	Precipitation (mm)	0,21	0,10	0,18	0,16	-0,03	0,82	0,17	0,17
	Tmean (°C)	-0,21	0,09	-0,17	0,17	-0,05	0,67	0,06	0,62
	Tmax (°C)	-0,19	0,13	-0,13	0,29	-0,07	0,56	0,03	0,84
	Tmin (°C)	-0,02	0,86	0,05	0,88	-0,02	0,88	0,23	0,07
July	Precipitation (mm)	**0.29(*)**	**0,02**	0,21	0,10	-0,10	0,42	**0.35(**)**	**0,01**
	Tmean (°C)	-0,21	0,09	-0,17	0,17	-0,05	0,67	0,06	0,62
	Tmax (°C)	**-0.26(*)**	**0,04**	-0,20	0,12	-0,02	0,90	-0,03	0,84
	Tmin (°C)	-0,03	0,81	-0,02	0,87	-0,11	0,37	**0.29(*)**	**0,02**
August	Precipitation (mm)	**0.26(*)**	**0,03**	**0.25(*)**	**0,04**	-0,05	0,68	**0.30(*)**	**0,02**
	Tmean (°C)	**-0.29(*)**	**0,02**	-0,22	0,08	-0,04	0,77	-0,11	0,38
	Tmax (°C)	**-0.34(**)**	**0,01**	**-0.25(*)**	**0,04**	0,00	0,99	-0,18	0,15
	Tmin (°C)	0,01	0,91	0,06	0,65	0,00	0,99	0,23	0,06
September	Precipitation (mm)	0,08	0,51	0,13	0,30	0,07	0,59	0,20	0,11
	Tmean (°C)	-0,09	0,48	-0,16	0,20	-0,20	0,11	-0,07	0,56
	Tmax (°C)	-0,11	0,38	-0,20	0,11	-0,18	0,16	-0,13	0,29
	Tmin (°C)	0,04	0,78	0,02	0,85	-0,14	0,28	0,11	0,39
October	Precipitation (mm)	0,02	0,86	0,03	0,80	-0,12	0,36	0,16	0,21
	Tmean (°C)	-0,01	0,95	0,03	0,79	0,14	0,28	0,08	0,53
	Tmax (°C)	-0,07	0,57	-0,02	0,85	0,18	0,15	-0,07	0,61
	Tmin (°C)	0,07	0,58	0,09	0,48	0,08	0,55	0,22	0,08
Growing season (March-October)	Precipitation (mm)	**0.38(**)**	**0,00**	**0.34(**)**	**0,01**	-0,05	0,69	**0.48(**)**	**0,00**
	Tmean (°C)	-0,13	0,29	-0,03	0,79	0,07	0,56	0,10	0,43
	Tmax (°C)	-0,21	0,09	-0,12	0,36	0,08	0,55	-0,01	0,91
	Tmin (°C)	0,14	0,28	0,23	0,07	0,14	0,27	**0.41(**)**	**0,00**

Tab. 3 - Maize, sugar beet, soybean and sunflower yield relationship with anomalies of *P* (mm), T_{mean} (°C), T_{max} (°C) and T_{min} (°C) on a monthly basis and for the whole GP in Vojvodina from1949 to 2013.
Tab. 3 - Mais, barbabietola da zucchero, soia e girasole: correlazione fra il rendimento e le anomalie di P (mm), Tmean (°C), Tmax (°C) e Tmin (°C) su base mensile.

did not adequately describe the growth of the leaves or taproot (Kenter *et al.*, 2006).

3.3.2. Temperature and crop yields

Investigated crop yields were insignificantly correlated with T_{mean} for whole GP. Analyzing the results during GP on a monthly basis, T_{mean} showed significant opposite influences on crop yields during spring and summer months. In March, sugar beet (P<0.01) and sunflower yields (P<0.05) showed significant positive correlation with T_{mean}, while significant negative correlation (P<0.05) was obtained between maize yield and T_{mean} in August. In other months, T_{mean} did not show significant correlation (P>0.05) with crop yields (Tab. 3). This suggests that higher temperatures in spring promote plant development, while excess heat in summer months has adverse impact on crop yields. Similar results were obtained in other countries. Mean temperatures and rainfall during July and August were strongly correlated with sugar beet yields in England (Freckleton *et al.*, 1999). From sowing to the end of June, the dry matter accumulation of both

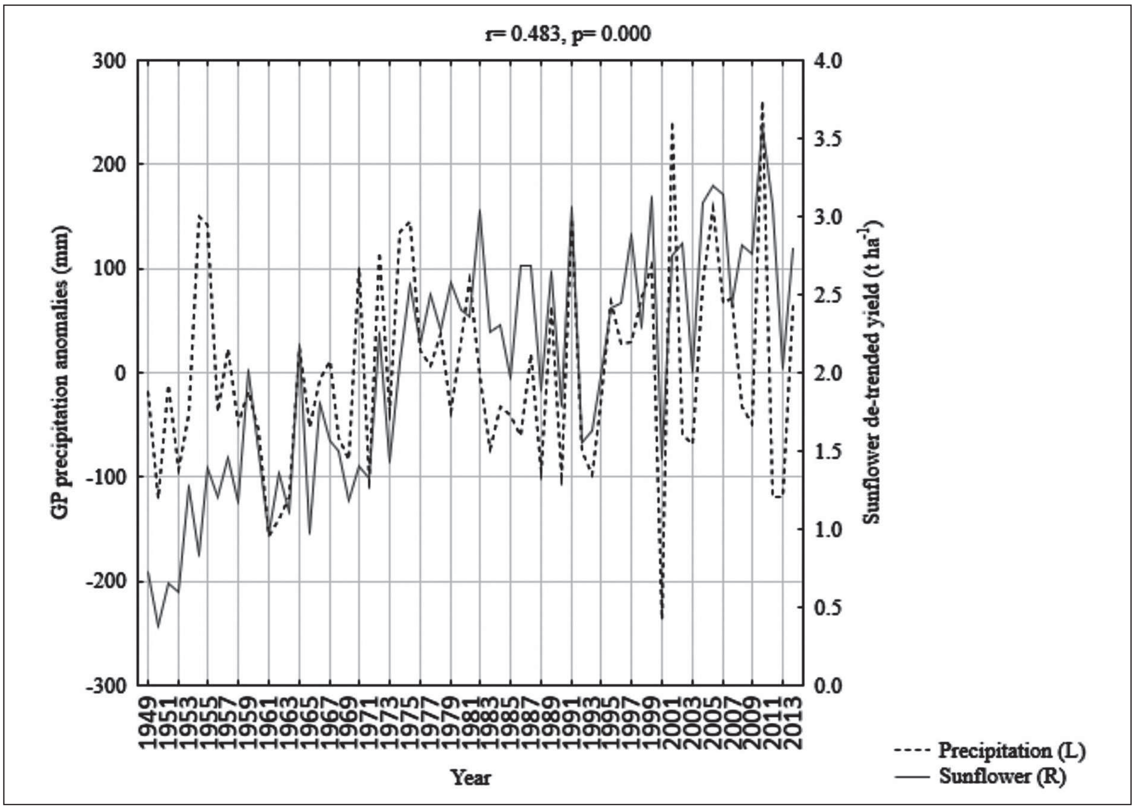

Fig. 4 - Time series of GP precipitation anomalies (mm) (dashed line) and sunflower de-trended yield (t ha^{-1}) (full line) in Vojvodina from 1949 to 2013.
Fig. 4 - Serie temporali di anomalie di precipitazione (mm) (linea tratteggiata) e del rendimento detrendizzato del girasole (t ha^{-1}) (linea completa) in Vojvodina 1949-2013.

leaves and taproot of sugar beet was strongly enhanced by increasing temperature (Kenter *et al.*, 2006). In years with higher temperatures in spring (months April to June) higher yields of sugar beet and maize were found in Czech Republic (Chloupek *et al.*, 2004). In the southern zone of Romania, maize produced less grain under higher summer temperature, but its yield increased with more summer rainfall (Cociu, 2012).

Tmax for whole GP was insignificantly correlated with crop yields. Analyzing the results during GP on a monthly basis, Tmax showed significant opposite impacts on crop yields during spring and summer months. In March, sugar beet yields showed significant positive correlation with T_{max} (P<0.05). Significant negative correlation (P<0.05) was obtained between maize yields and T_{max} in July, maize (P<0.01) (Fig. 5) and sugar beet yields and T_{max} in August (P<0.05). In other months, T_{max} did not show significant correlation (P>0.05) with crop yields (Tab. 3). This behavior suggests that higher maximum temperatures in spring promote plant development, while higher maximum temperatures in summer months lead to the reduction in crop yields. In the study of Bannayan *et al.*, (2011) maximum temperature was the main limiting factor of crop yields. Temperatures outside the range of those typically expected during the growing season may have severe consequences on crops, and when occurring during key development stages they may have a dramatic impact on final production, even in case of generally favorable weather conditions for the rest of the growing season (Moriondo *et al.*, 2011). Transitory or constantly high temperatures cause an array of morpho-anatomical, physiological and biochemical changes in plants, which affect plant growth and development and may lead to a drastic reduction in economic yield. The adverse effects of heat stress can be mitigated by developing crop plants with improved thermo-tolerance using various genetic approaches (Wahid *et al.*, 2007).

Sunflower yields were significantly correlated

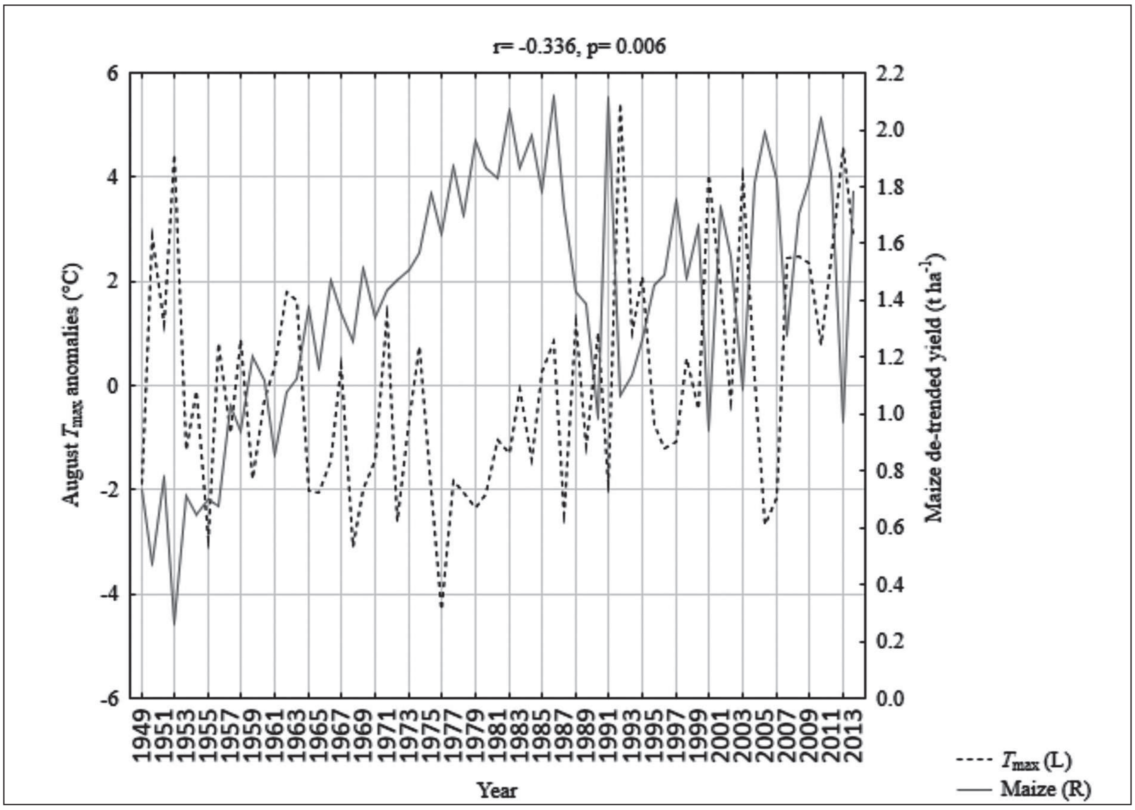

Fig. 5 - Time series of August T_{max} anomalies (°C) (dashed line) and maize de-trended yield (t ha^{-1}) (full line) in Vojvodina from 1949 to 2013.
Fig. 5 - Serie temporali di anomalie per le Tmax del mese di agosto (°C) (linea tratteggiata) e il rendimento detrendizzato del mais (t ha^{-1}) (linea completa) in Vojvodina 1949-2013.

(P<0.01) with T_{min} for whole GP. Analyzing the results during GP on a monthly basis, T_{min} showed significant positive correlations with crop yields during early spring and summer months. In March, sugar beet (P<0.01) (Fig. 6), sunflower (P<0.01) and maize yields (P<0.05) showed significant positive correlation with T_{min}. In July T_{min} was positively correlated (P<0.05) with sunflower yields (Tab. 3). This behavior suggests that higher minimum temperatures in spring prevent adverse impacts of cold weather and frost on plant development.

Improved understanding of the influence of climate on agricultural production is needed to cope with expected changes in temperature and precipitation (Rowhani *et al.*, 2011). It is expected that future climate change will lead to the increases in yield and expansion of climatically suitable areas in northern Europe. Disadvantages from increases in water shortage and extreme weather events (heat, drought, storms) will dominate in southern Europe (Bindi and Olesen, 2011). Among the adaptation options recommended by Bindi and Olesen (2011) to minimize the negative impacts of climate changes and to take advantage of positive impacts, changes in cultivar, sowing date, fertilization and irrigation, seem to be the most appropriate for the Vojvodina region.

4. CONCLUSIONS

The climate of Vojvodina, most important agricultural region in the Republic of Serbia, has changed in recent history. We observed 9 mm decade^{-1} increase of precipitation for whole GP and 0.2 °C decade^{-1} increase of mean, maximum and minimum temperatures for whole GP in 1949-2013 period. On a monthly basis, highest precipitation increase was in September (3.9 mm decade^{-1}) and highest temperature increase was in August with 0.3 °C decade^{-1} for mean, maximum and minimum temperatures.

Crop cultivation in Vojvodina is characterized by increase of harvested area, production and yield of all

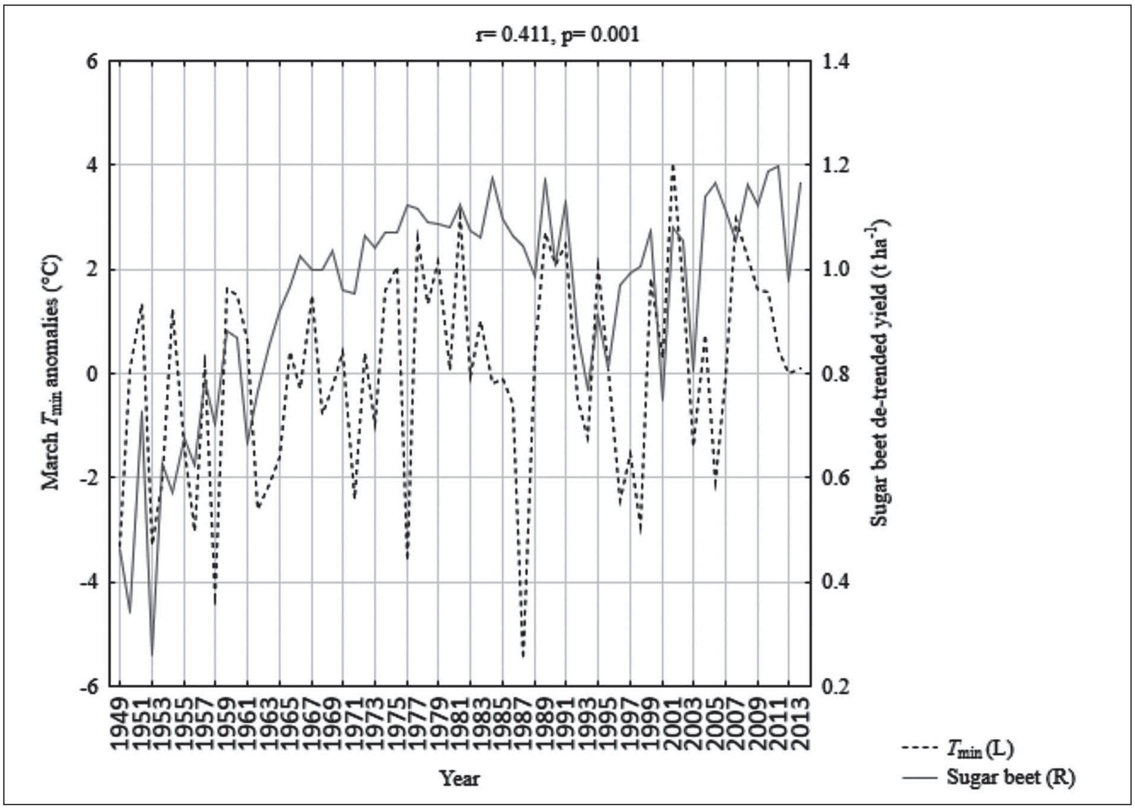

Fig. 6 - Time series of March T_{min} anomalies (°C) (dashed line) and sugar beet de-trended yield (t ha^{-1}) (full line) in Vojvodina from 1949 to 2013.
Fig. 6 - Serie temporali di anomalie per le Tmin del mese di marzo (°C) (linea tratteggiata) e il rendimento detrendizzato della barbabietola da zucchero (t ha^{-1}) (linea completa) in Vojvodina 1949-2013.

investigated crops. Soybean and sunflower showed highest increase of harvested area, while maize and sugar beet showed highest increase of production. Highest yield increase was for sugar beet (3.7 t ha decade^{-1}) and maize (0.5 t ha decade^{-1}), followed by soybean (0.3 t ha decade^{-1}) and sunflower (0.2 t ha decade^{-1}).
We also found that all crop yields, except soybean, were most responsive to changes in GP and summer precipitation. In Vojvodina, temperature values during March and summer months (July and August) were most responsive for crop yields. Maize yields showed significant negative correlation with mean temperature in August, maximum temperature in July and August and positive correlation with minimum temperature in March. Sugar beet yields exhibited strong positive responses to mean, maximum and minimum temperature in March and significant negative correlation with August maximum temperature. Sunflower yields showed significant positive correlation with minimum temperatures for whole growth period, March and July and with mean temperature in March. Only soybean yields did not show significant correlation with the investigated climate variables. Due to this, we can hypothesize that non-climatic influences such as improvements in crop genetics and technical factors were more responsive for soybean yields changes in the research period. We only considered recent changes in precipitation and temperature and did not project their future change that might have more pronounced effects on spring sown crop yields in Vojvodina.
Effects of precipitation and temperature variability on other crops development in Vojvodina should be investigated. Also, influences of important tele-connections that affect the weather in Europe (e.g. North Atlantic Oscillation, Arctic Oscillation, Mediterranean Oscillation, etc.) should be correlated with climate and crop data in Vojvodina in order to evaluate their role in precipitation, temperature and yields variability.

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