EVALUATION OF CLIMATE CONDITIONS WITH POSSIBLE INFLUENCE ON AGRICULTURAL PRACTICES IN CROATIA

Ivana Sestak[1], Darija Bilandzija[1], Milan Mesic[1], Marjana Gajić-Čapka[2]

[1]University of Zagreb, Faculty of Agriculture, Department of General Agronomy, Svetosimunska 25, 10000 Zagreb, Croatia
[2]Meteorological and Hydrological Service of Croatia, Department for Climatological Research and Applied Climatology, Gric 3, HR-10000 Zagreb, Croatia

Abstract

Climate variability has already significantly influenced agriculture and welfare of rural population in Croatia. To evaluate climate conditions and explain the impact of climate changes on crop production, the calculations have been performed for two subperiods: reference 30-year period 1961-1990 and the last two decades 1991-2010 at four meteorological stations with different climate conditions located across Pannonian, mountainous and Mediterranean agricultural regions of Croatia. Comparison of two periods was performed by calculation of mean annual cycles of temperature, precipitation and soil water balance on monthly scale, duration of period with air temperatures above temperature thresholds of 5, 10, 15 and 20°C, and linear trends. One extremely dry (2003) and one extremely wet (2010) year were additionally underlined for soil water balance analysis. Results show increase of duration in 1991-2010 period compared to reference period for all threshold temperatures. The highest increase in number of days (14 to 36) was recorded for 10°C for all stations, thus indicating warming process which affect most of the year. The second highest increase (13 to 64 days) was found for 20°C indicating more frequently occurrence of extreme hot weather during summer months. Water surplus during the period 1991-2010 was generally slightly increased in late autumn and early winter compared to the reference period, as the consequence of the precipitation increase.

Analyses of soil water balance at all observed stations indicate that the lack of precipitation in the year 2003 combined with high temperatures caused higher evapotranspiration and increased water deficit during late spring and summer months which negatively affected crop yields. The main characteristic of the wet year of 2010 was increased water surplus in months with optimal water supply or usually suffering from water shortage. Faster atmosphere warming during the second half of the 20th century and up to now is documented by the faster increasing trend in mean annual temperature during 1991-2010 than in the period 1961-1991 at all locations. During the 50-year period 1961-2010, annual amounts of precipitation show decreasing trends in NW Croatia, mountainous plateau and over the coastal region, except in the eastern lowland. Water shortages during growing season already played a critical detrimental role in winter wheat and maize yields in Croatia. Provision of sufficient water and favorable precipitation distribution may have a positive effect upon the agricultural production in the conditions of raised temperatures. For a good and efficient adaptation of agriculture to climate changes, new technologies and technical measures like adequate tillage systems, seeding dates and choice of appropriate seed should be implemented.

Keywords: climate, dry year, wet year, water shortage, crop production

Introduction

Recent climate changes and climate projections constitute a new challenge, with so far unknown demands upon agricultural science and practice. Food production should be tripled to feed the entire population of the Earth in the coming fifty years, that is, as much food has to be produced in that period as in the last 8000 years. It is obvious that this cannot be achieved by developing new agricultural areas since they are simply not available. Thus, increased production per unit area seems to be the only remaining solution to this problem. On the other hand, the soil is already under great pressure.

According to all estimates, if practicing modern intensive agriculture should attain production increase, its adverse effects on the environment, notably soil and water, would become an almost insolvable problem. Scenarios pointing to climate changes, involving the foreseen changes in temperature and precipitation, would additionally affect agriculture, as an activity governed by its own rules and regularities. Moreover, effects of climate trends and variability and disasters associated with weather conditions are more and more frequent in the whole world and in Croatia as well. Variability has already significantly influenced agriculture and welfare of rural population. For these reasons, detection of recent climate trends enable estimation of their impact on agricultural parameters, and the climate change scenarios should be recognized as a factor that will influence creation of a new approach to food production (*MZOPUG*, 2001).

Materials and methods

According to the objective of this paper to evaluate climate conditions and variability in air temperature and precipitation in Croatia during the last 50-year period and to explain the impact of climate changes on crop production, The data refer to the four meteorological stations characterized by different climate conditions and located across Pannonian (Zagreb – Maksimir: H=123 m asl, φ=45°49' N, λ=16°02' E, Osijek: H=89 m asl, φ=45°18' N, λ=18°20' E), mountainous (Gospic: H=564 m asl, φ=44°33' N, λ=15°23' E) and Mediterranean (Zadar: H = 5 m, φ = 44°08' N, λ = 15°13' E) agricultural regions of Croatia.

The calculations have been performed for two subperiods: reference 30-year period 1961-1990 and the last two decades 1991-2010. Comparison of two periods was performed by calculation of mean annual cycles of temperature, precipitation and soil water balance (after *Thornthwaite*) on monthly scale, dates of air temperature increase/decrease of 5, 10, 15 and 20°C and duration of period with air temperatures above temperature thresholds of 5, 10, 15 and 20°C and linear trends. Linear trends have been tested for significance by the non-parametric Mann-Kendall rank statistics t (*Mitchell et al.*, 1966; *Sneyers*, 1990). One extremely dry (2003) and one extremely wet (2010) year were additionally underlined for soil water balance analysis.

Effects of climate patterns on different agricultural crops cannot be foreseen with certainty. Still, according to the existing trends in temperature, precipitation and soil water balance, there is a possibility to point out the diversity of the problems that could appear in agricultural production in Croatia.

Results and discussion

Average annual cycle of mean monthly temperature for the recent period 1991-2010 has the same shape as for the reference period 1961-2010 (*Figure 1*). The largest differences are in summer and they are between 1 to 2°C per month. Higher monthly temperatures appeared also in January, more expressed in mainland than on the coast, and on average this amounts between 0.7 and 1.8°C.

Average annual cycle of monthly precipitation amounts changed the position of maximum in NW Croatia (Zagreb-Maksimir) from July to September (*Figure 2*). The average annual amount remains the same. In eastern lowland of Slavonia (Osijek) average annual amount increased about 11%, and contribution to this amount is mainly due to the increase in monthly precipitation in August, September and October. On the mountainous plateau of Lika (Gospic) the shape of the average annual precipitation cycle has remained the same, but with the intra-annual redistribution of monthly amounts. There has been the decline in seven months (February to August) and a more pronounced increase from September to December. Coastal middle Dalmatia (Zadar) had slight lower average annual amount in the last two decades with the most pronounced decrease in August, March and February.

It was also deemed useful to determine the beginning and the end of the period with daily temperatures above defined thresholds of 5, 10, 15 and 20°C, in order to analyze the possible impact on plant production influenced by temperature changes between two analysed periods (*Table 1*). Results show increase of duration in 1991-2010 period compared to reference period for all threshold temperatures. The highest increase in number of days (14 to 36) was recorded for 10°C for all stations, thus indicating warming process which affect most of the year. The second highest increase (13 to 64 days) was found for 20°C indicating more frequently occurrence of extreme hot weather during summer months.

Although Thornthwait's method for calculation of evapotranspiration is indirect, and includes the assumption that a maximum of 100 mm of water can be stored in soil, the advantage of estimating the water balance by this method is the fact that the required input parameters are air temperature and precipitation, climatological parameters generally available from the regular meteorological network at national meteorological service. According to the average values across years and stations, insignificant changes in water surplus, water shortage and optimal water supply have been recorded between reference period and 1991-2010 (*Figure 3*). Water surplus during the second period was generally slightly increased in late autumn and early winter, as the consequence of the precipitation increase in this period, which is in accordance to predictions of the RegCM model for Croatia (*MZOPUG*, 2010). When analyzing averages of two long-year datasets, the major variabilities in precipitation expressed by exchanging very dry and very wet years were masked. Soil water balance for two extreme years (2003 and 2010) showed large difference in seasonal pattern of water surplus and water deficit (*Figure 4*). Water deficit during 2003 was the main problem for all four locations which caused drought during critical crop phenophases and drastically reduced yields, especially in eastern part of Pannonian agricultural region (Osijek). These conditions were the consequence of high temperatures especially from May to August, and due to the precipitation less than normal all over the year except in January and October.

The main characteristic of the wet 2010 was increased water surplus in autumn months in NW Croatia (Zagreb-Maksimir) when there is normally optimal water supply. In eastern lowland (Osijek) water surplus was in months with optimal water supply or usually suffering from water shortage, which was the reason for floods and high damages in crop production represented by reduced yields. In Zadar region water surplus was increased from November to March, the period of the year when water surplus is also present in normal climate conditions. On the mountainous plateau of Lika (Gospić) the soil water balance components through the year were quite different to the average regime. Exceptional water surplus in winter months and in May were the consequence of large precipitation amounts, which were above or even extremely above normal. The water shortage in August 2010, which is not expected in an average year for the mountainous region, appeared because of the simultaneous absence of rainfall and extremely high temperatures that caused high evapotranspiration (*DHMZ*, 2010).

Analyses of soil water balance at all observed stations indicate that the lack of precipitation in the year 2003 combined with high temperatures caused higher evapotranspiration and increased water deficit during late spring and summer months.

Trends in mean annual temperature within the 50-year period 1961-2010 are statistically significant at inland locations (Osijek and Zagreb-Maksimir) and at middle Dalmatian coast (Zadar) (***Figure 5***). Faster atmosphere warming during the second half of the 20th century and up to now is also documented by the faster increasing trend during 1991-2010 than in the period 1961-1991 at all locations.

In future climate, temperature at 2 m will be increased, which is statistically significant even at the 99% confidence level (*MZOPUG*, 2010). This will be more pronounced at the littoral than in inland.

During the 50-year period 1961-2010, annual amounts of precipitation show decreasing trends in NW Croatia (Zagreb-Maksimir), mountainous plateau (Gospić) and over the Zadar region, except in the eastern lowland where the positive trend is present (***Figure 4***). Trends for 30-year period 1961-1990 show decrease in precipitation.

According to the future clime projections for Croatia (*MZOPUG*, 2006, 2010), there will be the decrease in total precipitation in three seasons (spring, summer and autumn), primarily in the coastal, southern and mountainous Croatia. Only in winter there will be a slight precipitation increase, mainly in the littoral and mountainous part of Croatia, as well as in the northern and eastern parts.

By the insight into climate variability patterns over 50-year period, it is evident that climate change intensity and direction will gradually bring significant changes in plant production systems. According to the results for all observed stations except Zadar, a very variable annual water balance conditions can be found during years with extreme precipitation pattern – a pronounced surpluses all over the wet year and a significant shortage during summer in the dry year (***Figure 3***).

Also, annual number of days with temperature above 20°C was increased for 13-64 days in period from 1991-2010 compared to the reference period. For this reason and based on precipitation and temperature trends, the probability of dry periods in summer months will be increased, which will have an essential influence on yield decrease unless enough water is provided for spring crops. Severe droughts were already recorded in 1992, 1995 and 1998, and those of the years 2000 and 2003 were proclaimed natural disasters (*MZOPUG*, 2006).

Damage caused by existing climate conditions and climate variability already has an important impact on agriculture in Croatia. If such trends continue, present technology of agriculture plant production will suffer great changes. The total amount, distribution, form and intensity of precipitation are highly important for plant production.

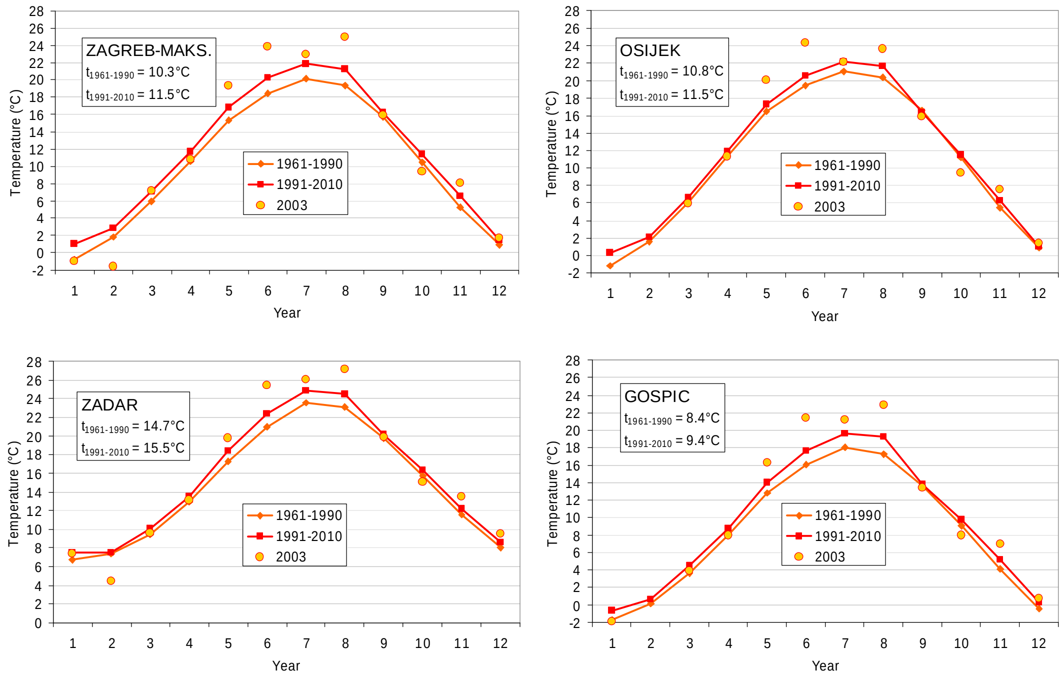

Figure 1 Annual cycle of mean monthly temperature for two periods: 1961-1990 and 1991-2010 and 2003

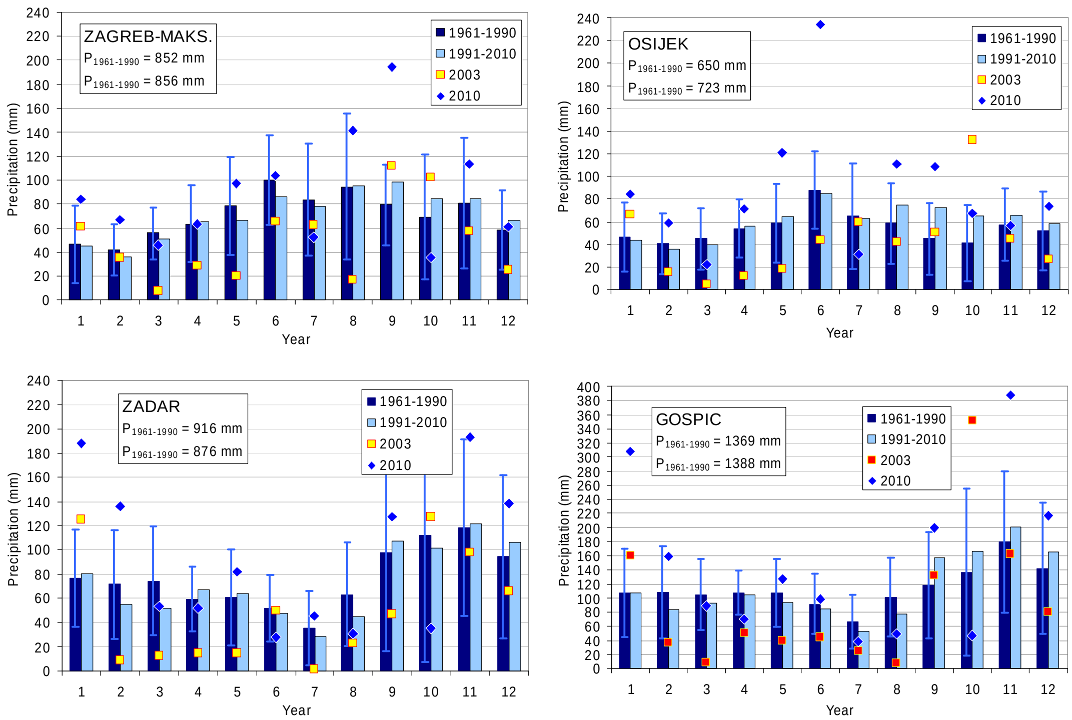

Figure 2 Annual cycle of mean monthly precipitation for two periods: 1961-1990 and 1991-2010, interval [P+sd, P-sd] for the referent period 1961-1990, and monthly amounts for 2003 and 2010

Table 1 Dates of air temperature increase/decrease for different temperature thresholds and duration of periods above these thresholds at four meteorological stations

Meteorological stations	Period	Temperature thresholds											
		5°C			**10°C**			**15°C**			**20°C**		
		B	**E**	**D**	**B**	**E**	**D**	**B**	**E**	**D**	**B**	**E**	**D**
Zagreb Maksimir	1961-1990	9.III.	17.XI.	254	11.IV.	18.X.	191	13.V.	19.IX.	130	13.VII.	21.VII.	9
	1991-2010	1.III.	24. XI.	269	20.III.	24.X.	218	4.V.	23.IX.	143	12.VI.	23.VIII.	73
Osijek	1961-1990	9.III.	18.XI.	255	7.IV.	22.X.	199	6.V.	24.IX.	142	25.VI.	18.VIII.	55
	1991-2010	5.III.	22.XI.	263	21.III.	24.X.	218	2.V.	24.IX.	146	10.VI.	25.VIII.	75
Zadar	1961-1990	-	-	-	21.III.	28.XI.	253	29.IV.	21.X.	176	7.VI.	13.IX.	99
	1991-2010	-	-	-	18.II.	3.XII.	289	24.IV.	25.X.	185	28.V.	16.IX.	112
Gospic	1961-1990	25.III.	9.XI.	230	27.IV.	9.X.	166	5.VI.	3.IX.	91	-	-	-
	1991-2010	19.III.	16.XI.	243	17.IV.	13.X.	180	24.V.	8.IX.	108	-	-	-

B – beginning of period; E – end of period; D – duration in days

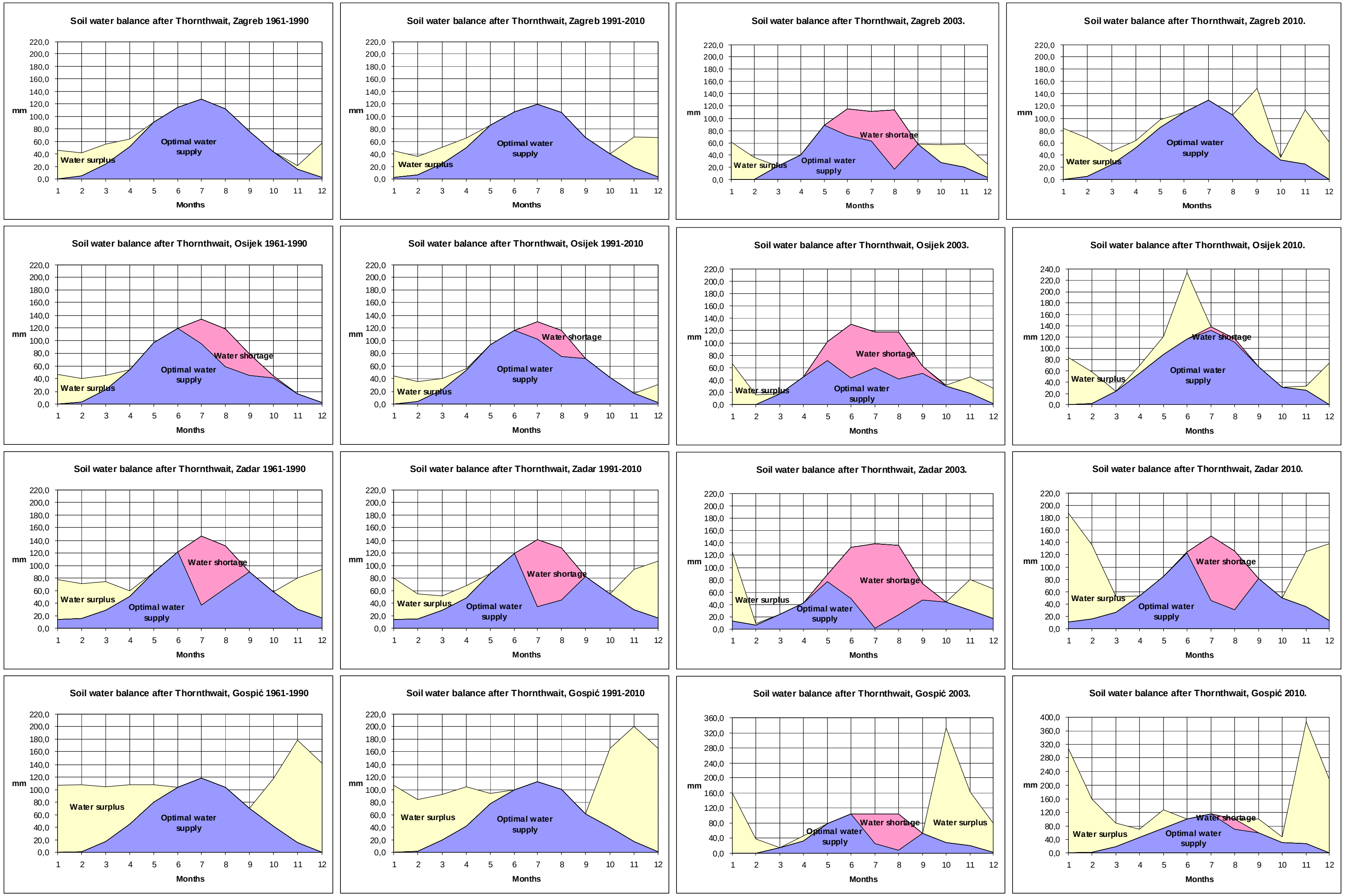

Figure 3 Soil water balance after *Thornthwait* for the periods 1961-1990 and 1991-2010 and extreme years (2003 and 2010) for four meteorological stations.

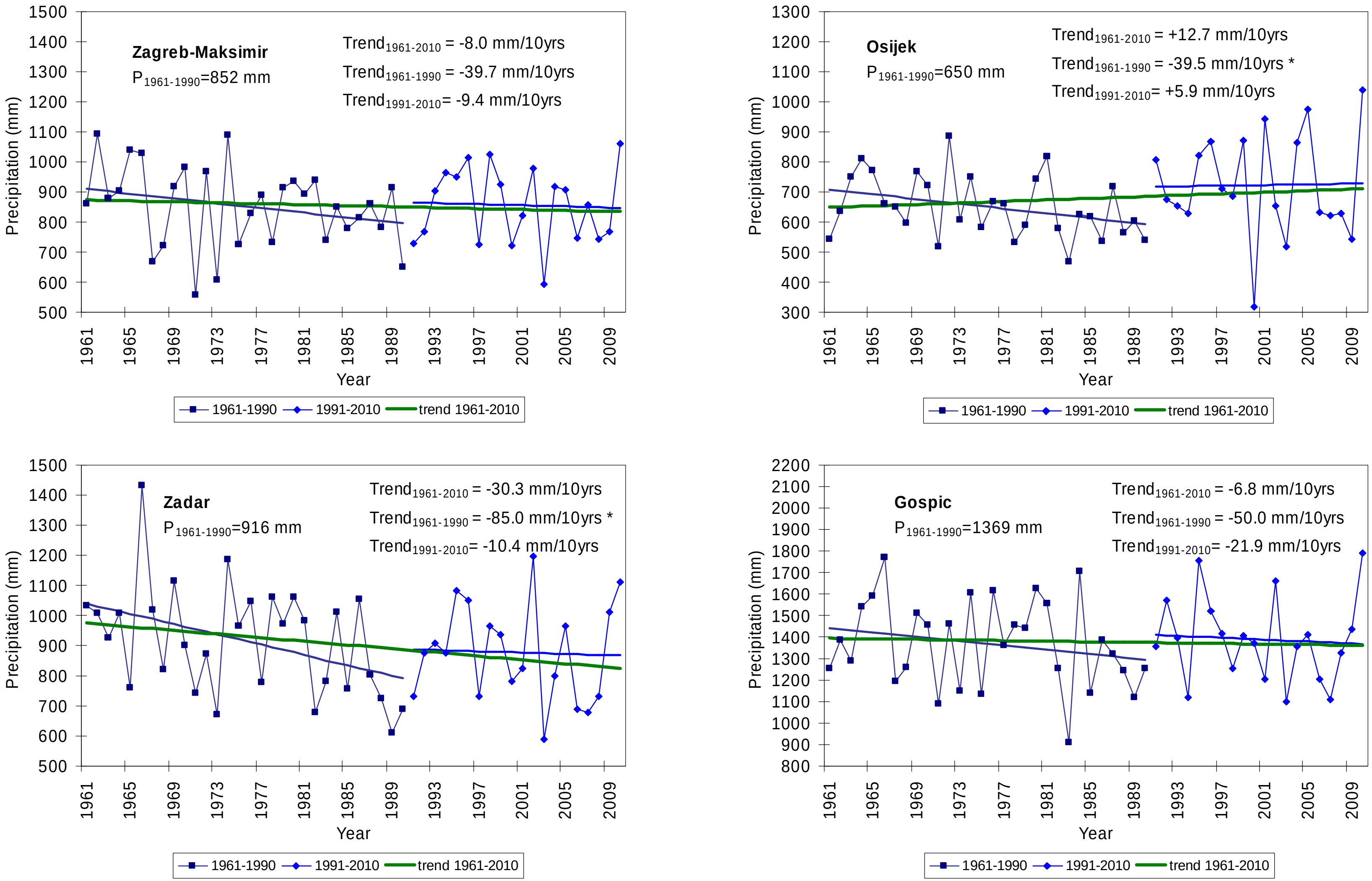

Figure 4 Time series of annual precipitation and fitted linear trends for the periods: 1961-2010, 1961-1990 and 1991-2010.

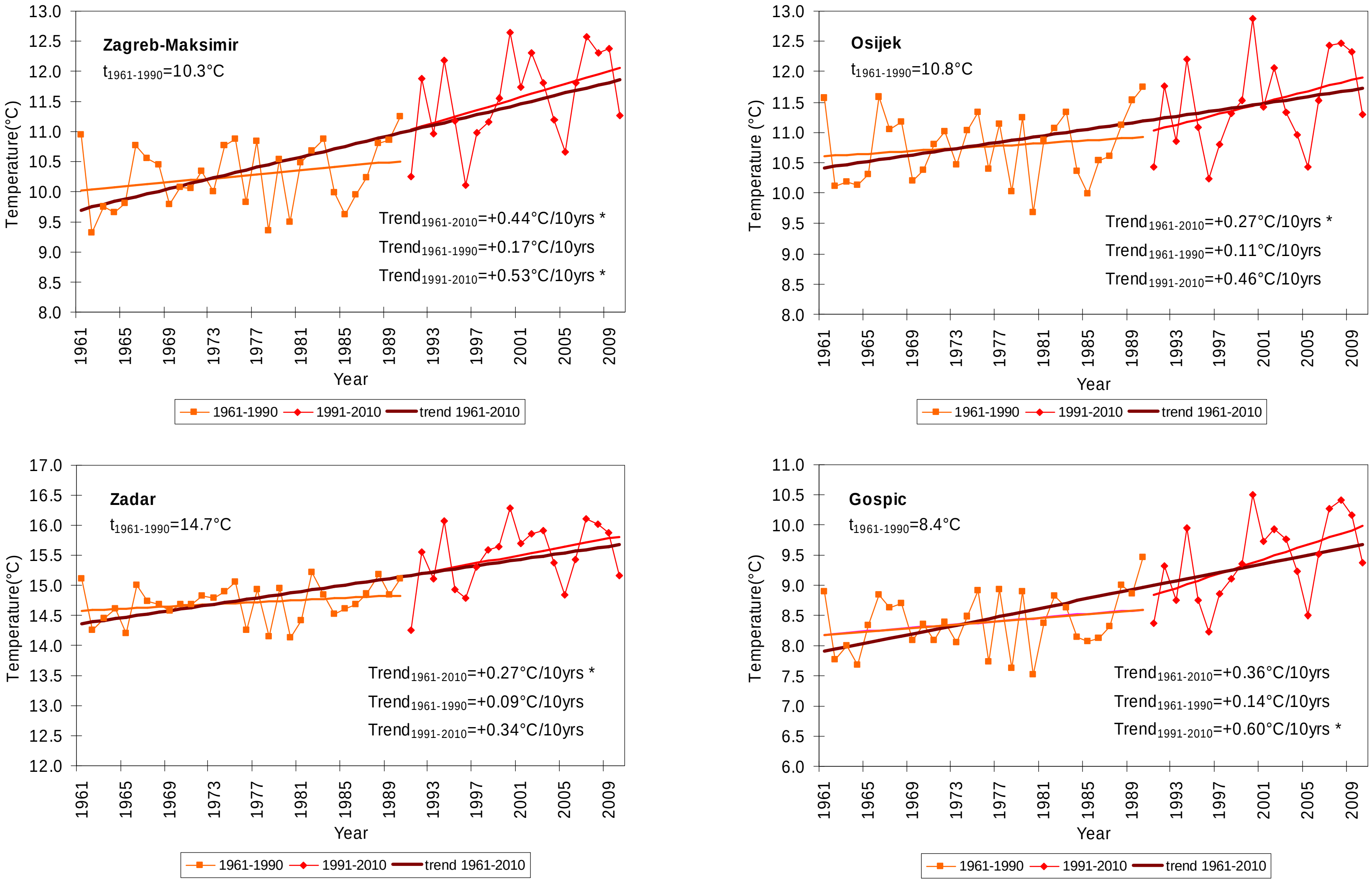

Figure 5 Time series of mean annual air temperature and fitted linear trends for the periods: 1961-2010, 1961-1990 and 1991-2010.

For modern agriculture it is important to maintain the soil water balance in favorable condition, while in future such condition will be even more emphasized. Beside combination effects of various climate factors on a result in production of some crops (winter wheat, maize), other edaphic, economic and social factors influenced as well. Such combinations will be crucial for agriculture development in the future as well, along with probable development of new techniques, including precision farming, robots, etc. Modern technology in wheat and maize cultivation enabled that today, along with the utilization of equal or smaller agricultural land, the yields are significantly increased. If the yields analysis is performed, it is easy to determine a crucial impact of weather conditions during some years when yields were quite lower than the average. The most common case of yields decrease is conditioned by water shortage but all other meteorological factors, which in various combinations influenced the yields realization in Croatia, are of great importance as well.

Unfavorable weather conditions during vegetative season played a critical detrimental role in winter wheat crop yields, averaging to lower yields every fifth year during the last 50 years. Majority of the adverse impact is caused by water shortages during critical phenophases, followed by other factors such as surface water stagnation, frost, inability to adhere to optimal agrotechnical terms, etc. Maize crop yield in Croatia is mostly limited due to water shortages during flowering and fertilization phases and kernel starch filling. In the last 20 years there were 4 years with extremely low maize yields, usually due to droughts (*MZOPUG*, 2001).

According to trends, it may be assumed that seeding of spring crops will commence at an earlier date and, depending on the possibility of providing sufficient irrigation water, the growing period will last longer. Yields would be constrained by the length of the growing period, provision of sufficient water for intensified evapotranspiration, and possible crop damage due to early spring frosts as well as excessively high temperatures in summer months. Winter crops will have more favorable conditions for growth and development, so some yield increases may be expected. Spring crops will suffer from water deficiency in summer months unless sufficient water is provided for irrigation, in some years yields may be substantially reduced due to droughts. Besides irrigation, adverse effects of water deficiency may be also avoided by the application of adequate tillage systems for a given region, seeding dates, choice of appropriate seed, etc.

In mountain regions (Gospic), there is still enough water according to the current average water balance values. Based on the duration of particular temperature thresholds, prolongation of the growing period from 13 to 17 days was recorded in period 1991-2010. Due to the highest significant trend of temperature increase in the last 20 years (+0.60°C/10yrs), it might have a good effect on yields of field crops. Higher air temperatures influence earlier emergence and faster going through particular phenophases. On the other hand, faster initial growth in spring increases the risk of crop impairment by frost. The expected temperature increase should provide enough warmth for thermophilic crops. In coastal part (Zadar) temperatures above 10°C would practically last throughout the year (Table 1). If not enough water can be provided, part of the drought associated problems could be solved by shifting seeding times to periods with sufficient precipitation.

Without significantly higher precipitation and with the expected increase in evapotranspiration, the largest part of the lowland and coastal parts of Croatia will be exposed to drought hazards. This also holds for summer months in mountain regions, particularly with respect to the water-holding potential of Karst soils (*MZOPUG*, 2001). The main problems are extreme climatic conditions with unfavorable annual distribution of precipitation and raising temperature which alternate between years. However, provision of sufficient water or a favorable precipitation distribution may have a positive effect upon the yields of agricultural crops in the conditions of raised temperatures.

Although climate change present a certain risk for the future, there are multiple steps that can be taken today in order to resolve current climate vulnerability problem. Precise, economically and ecologically acceptable adaptation measures to climate change in various agroecological conditions are yet to be worked out in details. Surely, it would be measures according to which adaptation capacities will be created (in terms of performing the research, developing and applying the model for impact simulation, as well as climate change adaptation, etc.), technical measures presuming, for example, increase of carbon content in the soil, wider crop rotation, implementation of fast growing crops, etc.), investing into irrigation and other. Within the MFCAL concept (*Multifunctional character of agriculture and land*) other possibilities of implementing new technologies, which could be useful for agriculture adaptation to climate change, should be searched for as well. Obstacles are numerous, but they can be overcome by proper activities. These activities mean more investments into researches, as well as education of all included into agriculture sector (*MZOPUG*, 2010).

For a good and efficient adaptation of agriculture to climate changes, naturally to the extent that it is possible, the following should be undertaken (*MZOPUG*, 2001):

- Preparations for own production or procurement of agricultural machinery and equipment that will enable application of new practices and new soil tillage methods, adapted to the changed climate conditions, such as no-tillage, direct drilling, minimal tillage, ridge-tillage, and other forms of conservation tillage, adapted to water surplus/deficiency, stronger winds, rains of higher intensity, higher temperatures, etc.
- The time and depth of application of particular plant-growing practices, such as ploughing, sowing, fertilization, topdressing, pest protection, etc., will have to be adapted to the changed climate conditions.
- Plant breeding – creation of varieties and hybrids resistant to more severe droughts or higher humidity should ensure stable production.
- Choice and adequate, rotation of winter and spring crops, high-density crops and row crops, as well as crops with longer and/or shorter growing periods, in compliance with the new changed climate conditions.
- Development of new agricultural areas. Croatia, however, does not have great potentials in this respect because of mainly marshy areas, which in turn have an ecological role and importance of their own.
- Reintroduction of old, domestic cultivars that used to be grown in these parts.
- The role of wind in our conditions should be specially emphasized. Soil erosion by wind which, though neglected, has been causing great damage, will become an even more serious problem, notably on sandy soils in the Sava valley and on light soils in eastern Croatia.
- Besides its effect on soil erosion, wind will have a stronger influence on the distribution of pollutants, emitted from industrial and urban areas, as well as roads

into the environment. Thus, excessive pollution will occur on the sites where solid particles from air are deposited. These reasons justify our assumption of windbreaker belts gaining on importance.

- Wind will also have a major role in salinization/alkalization of soils in the coastal region, as well as in damage incurred to agricultural crops by increasing occurrence of rime frost.
- For the said reasons, slope exposition will gain on importance. Northern sides will be subjected to more intensive water erosion, so crop rotation and tilling practices will have to be adapted to the new conditions.

For efficient adaptation of agriculture to climate change, surely up to possible dimensions of that adaptation, it is important to invent and to continuously perform research programs in agriculture.

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