Analysis of Climate Elements in Central and Western Istria for the Purpose of Determining Irrigation Requirements of Agricultural Crops

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Summary

A consequence of climate changes is an increasing frequency of drought, which on average occurs in Croatia every third to fifth year and during the vegetation period it can reduce crop yield significantly. The aim of the research is both to determine crop water requirements in an average and in a dry year and to determine the decline in crop yields in an average and in a dry year. The multi-annual climate data series for a 30-year period, 1981-2010 from station Pazin in central Istria and 1981-2010 from Poreč in western Istria was used. Based on these data, a reference evapotranspiration was calculated for an average and a dry year using the Penman-Monteith method through "Cropwat" software. The crop water requirement for five different crops is determined by soil water balance using the Palmer method (Palmer, 1965), corrected according to Širić and Vidaček (1988), using "Hidrokalk" software. Crop response to the lack of soil water and yield decline were determined according to the method published by Doorenbos and Kassam (1979). Correlation test was used to determine correlation between precipitation and crop yields. In central Istria, water shortage in an average year ranged from 3.4 mm (olives) to 110.7 mm (alfalfa) and yield decline ranged from 1.1% (olives) to 18.6% (alfalfa), while in a dry year water shortage ranged from 43.2 mm (olives) to 229.5 mm (alfalfa) and ranged from 10.3% (olives) to 37.7% (alfalfa). In western Istria, in an average year water shortage ranged from 35.5 mm (olives) to 239.7 mm (alfalfa) and yield decline ranged from 7% (olives) to 40.2% (tomatoes), and in a dry year water shortage ranged from 74.4 mm (olives) to 288.9 mm (alfalfa) and yield decline ranged from 14.4% (olives) to 40.7% (alfalfa). The determined water shortage and reduced yields are sufficient indicators of irrigation requirements in Istria.

Key words

climate elements, central and western Istria, agricultural crops, irrigation

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Introduction

Over the last decades, climate change is a burning issue and a major world problem and therefore solutions are being sought to mitigate / prevent its consequences. Climate change can be represented as a change in climate elements (temperature, precipitation, humidity, wind, insolation) relative to average values or as a change in the distribution of climate events relative to average values. Climate change causes more frequent occurrences of floods and droughts, which can cause major damage to agriculture and the environment. As a consequence of climate change, the rise in frequency and intensity of extreme weather events, such as drought, heavy rain and gales, among others, has a negative impact on yields and their quality (Mađar et al., 1998; Fischer et al., 2005; Parry et al., 2005; Kovačević et al., 2013; Dokić et al, 2015).

The yields of agricultural crops fluctuate over many years and are influenced by many abiotic and biotic factors. A large number of studies indicate that crop yields primarily vary as a result of extreme climate conditions, although other factors, such as soil fertility, the applied agro-technology and plant species may also affect crop yields (Kovačević and Josipović, 2015; Tomić et al., 2020).

Climate characteristics and soil water regime, as well as their variable and complex interrelations, define the efficiency of plant production (Šimunić et al., 2007). According to Beltrão et al. (1996), the highest yields are obtained at the time of the most favourable air-water ratio in the soil, mainly in the critical periods for each crop.

Due to increasing frequency of droughts, varying intensity and duration in Croatia, the project "Plan of Irrigation and Agricultural Land Management in the Republic of Croatia" (Romić et al., 2005) was adopted, which strives to define favourable conditions for planned and less risky agricultural production. Within the previously mentioned project, the planning and implementation of irrigation in the area of Istria County was started and this article is based on the results obtained from recent studies.

The specific objective of this research is to determine crop water requirements in an average and in a dry year in central and western Istria and to determine crop yield decline in those years.

Materials and methods

For the central part of Istria, the multi-annual climate data series for a 30 – year period (1981–2010) from the main meteorological station Pazin and for the western part of Istria, the data series of the same length, but for the period (1986–2015) from climatological station Poreč was used. Based on the climate data, a reference evapotranspiration was calculated for an average and a dry year (probability of occurrence in 25% cases). The reference evapotranspiration was calculated using the Penman-Monteith method through "Cropwat" software version 8.0. Crop water requirement was determined by soil water balance using the Palmer method (Palmer, 1965), corrected according to Širić and Vidaček (1988), using "Hidrokalk" computer program and its explanation is in text that follows. For soil water balance calculation, the corresponding values of effective precipitation for an average and a dry year were used, which was calculated by USDA, SCS method. The values of soil water constants for each area were taken into account as the average of the values of the most represented soil type, red soil – terra rossa (Husnjak, 2014), as shown in Figure 1. The soil studied in central Istria had the following characteristics: field water capacity was 42 vol% and wilting point was 19 vol%, while in western Istria the value of field water capacity was 45 vol% and wilting point was 21 vol%. Crop water requirements and yield decline were related to five crops: tomatoes, cabbage, alfalfa, vineyards and olives. The root depth for the calculation of soil water balance was 30 cm (tomatoes, cabbage and alfalfa), 50 cm for the vineyard and 60 cm for olives. Concerning all the previously mentioned crops, the vegetation period was considered and phenological phases and their duration were determined. Each phenological phase was corrected by the crop coefficient.

Crop yield decline was determined according to the method published by Doorenbos and Kassam (1979).

$$\left(1-\frac{Ya}{Ym}\right)= ky\left(1-\frac{ETa}{ETc}\right) \qquad (1)$$

Ya – Actual yield

Ym – Maximum possible yield

ky – Yield response factor

ETa – Actual evapotranspiration

ETc – Crop (maximum) evapotranspiration.

Correlation test was used to determine correlation between precipitation and crop yields.

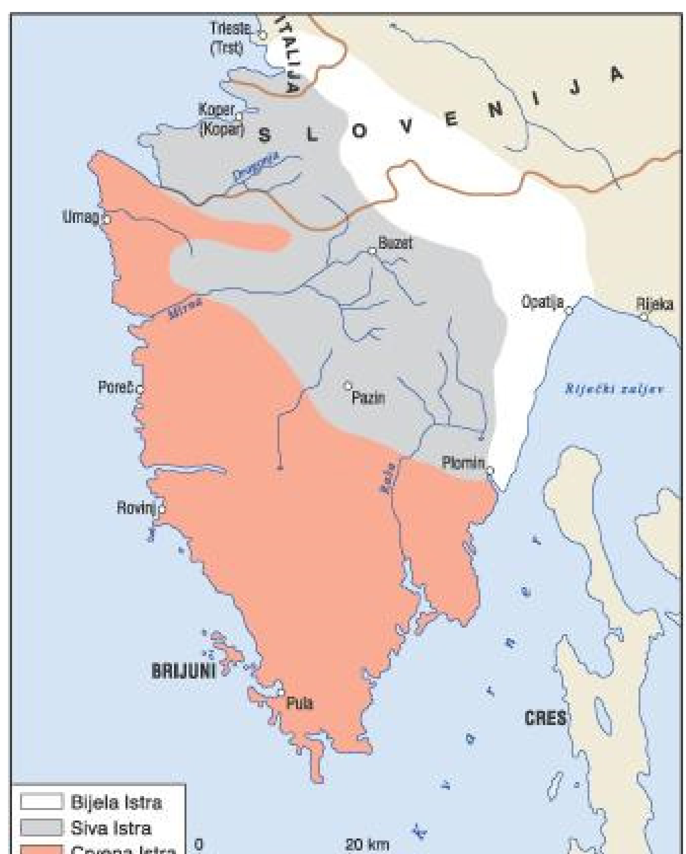

Figure 1. Geomorphological areas of the Istrian peninsula (Source: http://istra.lzmk.hr/clanak.aspx?id=957)

Results and discussion

Annual air temperature, annual precipitation amounts and corresponding trends for meteorological stations (MS) Pazin and Poreč are presented in Figures 2a, 2b, 3a and 3b.

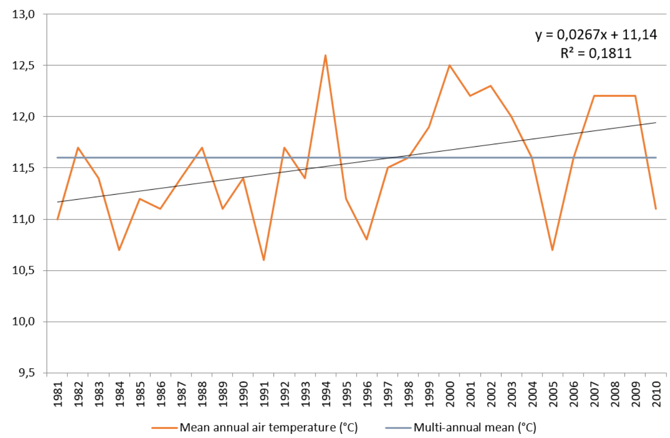

Figure 2a. Mean annual air temperature (°C), multi-annual mean and corresponding linear trend of mean annual air temperature for MS Pazin

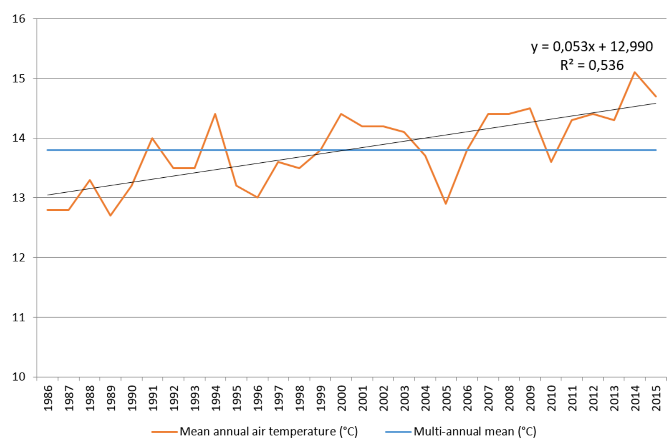

Figure 2b. Mean annual air temperature (oC), multi-annual mean (°C) and corresponding linear trend of mean annual air temperature for MS Poreč

The precipitation regime is one of the most variable climate characteristics of some area, both spatially and temporally (Croatian Meteorological and Hydrological Service and Croatian Meteorological Society, 2003). This can also be seen in the area of Pazin and Poreč.

During the observed period, at MS Pazin mean annual air temperatures ranged from 10.6°C to 12.6°C while multi-annual mean air temperature was 11.6°C. The corresponding linear trend of mean annual air temperature is 2.67°C/100 yrs, which is evident from Figure 2a. During the analysed period (1986-2015) at MS Poreč mean annual air temperatures ranged between 12.7°C and 15.1°C. The multi-annual mean air temperature was 13.8°C, higher than at MS Pazin. The corresponding mean annual air temperature trend for MS Poreč is 5.3°C/100 yrs, which is shown in Figure 2b. The positive mean annual air temperature trend is evident for both stations. The above mentioned indicates that the air temperature trend in Istria is in accordance with the global warming trend, with some inter-annual variations. During a 30-year period, positive air temperature trend is evident on both meteorological stations located in central and western part of Istria, which could be an indicator of climate change. According to Kutilek and Nielsen (2010), the average temperature increased by 1.1-1.3oC in 100 years in Central Europe. The effects of climate change have become increasingly evident over the past decades (Patt and Schröter, 2008). Positive trends of air temperature and precipitation amounts in their research have been quoted by Šimunić et al. (2013 and 2019) and Miseckaite et al. (2018).

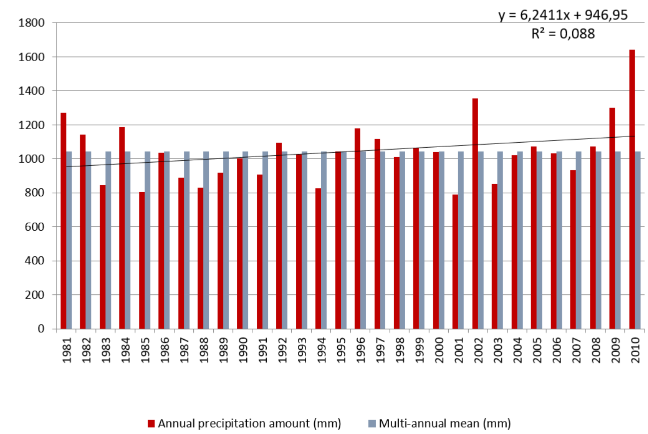

Figure 3a. Annual precipitation amount (mm), multi-annual mean (mm) and corresponding linear trend of annual precipitation amount for MS Pazin

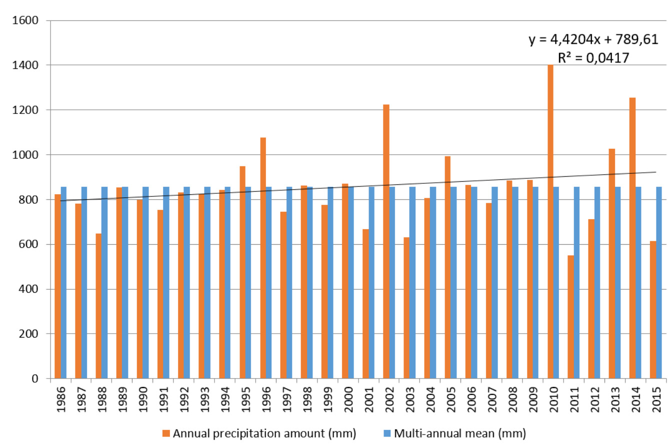

Figure 3b. Annual precipitation amount (mm), multi-annual mean (mm) and corresponding linear trend of annual precipitation amount for MS Poreč

Concerning MS Pazin, annual precipitation amounts were within the range from 791.0 mm to 1642.0 mm, while multi-annual mean of precipitation amounts was 1043.7 mm. Within the 30-year period the difference between the maximum and the minimum value of annual precipitation amount was 851 mm. On the other hand, for MS Poreč annual precipitation amounts were within the range from 549.7 mm to 1403.3 mm. The multi-annual mean of annual precipitation amounts for MS Poreč was 858.1 mm, which is comparable to the previously mentioned mean for MS Pazin. During the analysed period for MS Poreč, the difference between the maximum and the minimum value of annual precipitation amounts was 853.6 mm.

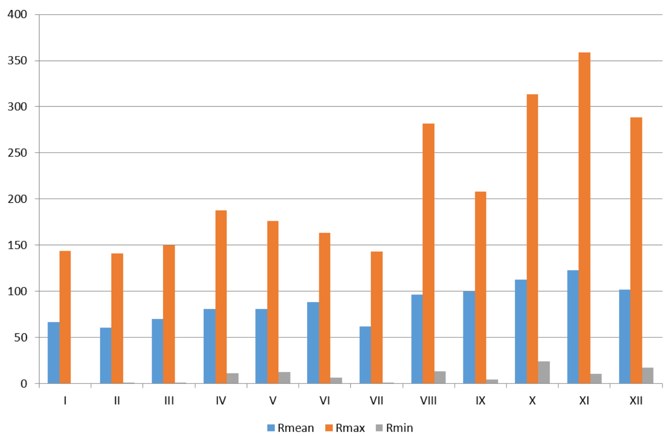

Figure 4a. Annual variation of the mean, the maximum and the minimum values of monthly precipitation amounts. The multi-annual mean of annual precipitation amounts is 1043.7 mm, MS Pazin (1981-2010)

The annual course of monthly precipitation amounts in Croatia can be divided into two types (Zaninović et al., 2008), depending on the time of the year when the month with the lowest precipitation amount occurs: the maritime type of annual course, with the lowest precipitation amount occurring during the warm period of the year (April to September), and the continental annual course, with the lowest precipitation amount occurring during the cold half of the year (October to March). The annual course of monthly precipitation amount for MS Pazin has characteristics of continental precipitation regime (Figure 4a). The main maximum is in late autumn, in November (358.7 mm). The lowest precipitation amount can be expected in February (141.0 mm). Monthly precipitation amounts can vary significantly from year to year. The variability of monthly precipitation amounts (expressed by the coefficient of variation) is large with the maximum in October (0.71) and the minimum in June (0.45). On the other hand, MS Poreč has the maritime type of the annual course of monthly precipitation amount (Figure 4b) with the maximum precipitation amount in October (279.4 mm) and the minimum in April (126.3 mm).

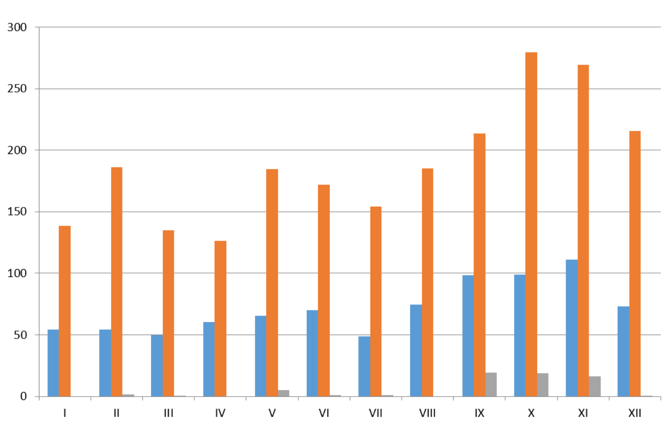

Figure 4b. Annual variation of the mean, the maximum and the minimum values of monthly precipitation amounts. The multi-annual mean of annual precipitation amounts is 1043.7 mm, MS Poreč (1986-2015)

As previously shown, the difference between the maximum and the minimum value of annual precipitation amount for the above-mentioned station is almost the same. There are some differences in annual precipitation amounts from year to year, which is described by the coefficient of variation. A greater variability of annual precipitation amounts is obvious for MS Poreč. In addition, MS Pazin and Poreč have positive trends of annual precipitation amount, 624.1 mm/100 yrs and 442.0 mm/100 yrs, respectively. The trends of precipitation extremes in Europe vary greatly and depend not only on the region, but also on the indicator used to describe an extreme (Groisman et al., 2005). Changes in precipitation are the prime drivers of change in the availability of both surface water and groundwater resources (Beare and Heaney, 2002). Changes in precipitation amount and its distribution have direct influence on soil water content and affect crop cultivation.

The relationship between reference evapotranspiration and effective precipitation

Reference evapotranspiration that integrates the effects of climate elements and indicates the overall evaporation has been presented in Table 1a and 1b. In the same tables has been presented and the relationship between reference evapotranspiration and effective precipitation, both for multi-annual mean and dry year.

Tables 1a and 1b show that multi-annual mean reference evapotranspiration was 980.0 mm or 2.7 mm.day-1 and it was higher than reference evapotranspiration based on the frequency of the occurrence of climate elements upon 25% precipitation probability, which was 918.1 mm or 2.5 mm.day-1. Moreover, with a multi-annual mean of climate elements, the daily evapotranspiration is higher during the vegetation period than in the year with the frequency of the occurrence of climate elements upon 25% precipitation probability. In relation to effective precipitation for the multi-annual mean and reference evapotranspiration calculated on the basis of multi-annual climate elements, Tables 1a and 1b shows that the difference in water shortage is smaller than in effective precipitation at the frequency of occurrence in 25% of cases and reference evaporation calculated on the basis of associated climatic elements. In both cases, precipitation deficit occurs throughout the growing season. The exact crop water deficit in the focus of this research can be determined by the soil water balance.

Crop water requirements in average and dry years

Soil water balance determined crop water requirements and water deficit in average and dry years for the central and western part of Istria (Tables 2a and 2b).

As shown both in Table 2a and in 2b there was a difference in soil water deficit in the central and in the western part of Istria. A smaller deficit for all crops was recorded in the central part of Istria, both in average and in dry years compared with the western part of Istria. This can be related to the precipitation amount and the average annual air temperature. The area of central Istria has a multi - annual average of 1044 mm of precipitation, and the western area 854 mm. Apart from the difference in precipitation amount, there is also a difference in the average air temperature. In the central part of Istria, the average air temperature was 11.6°C,

Table 1a. Relationship between effective precipitations, multi-annual mean and dry year and reference evapotranspiration based on multi-annual mean of climate elements and based on the frequency of the occurrence of climate elements upon 25% precipitation probability in the central part of Istria (Pazin)

Month	Multi-annual mean (mm)		Difference	Dry year (mm)		Difference
	Effective precipitation	ETo		Effective precipitation	ETo	
Jan	59.4	18.6	40.8	34.8	21.7	13.1
Feb	54.7	28.0	26.7	48.5	25.2	23.3
Mar	62.2	49.6	12.6	21.2	52.7	-31.5
Apr	70.7	72.0	-1.3	62.2	66.0	-3.8
May	70.2	102.3	-32.1	126.9	80.6	46.3
June	75.7	120.0	-44.3	65.2	117.0	-51.8
July	55.9	142.6	-86.7	35.7	142.6	-106.9
Aug	81.7	120.9	-39.2	47.7	127.1	-79.4
Sep	83.9	75.0	8.9	17.5	84.0	-66.5
Oct	92.4	46.5	45.9	73.4	46.5	26.9
Nov	98.8	27.0	71.8	150.4	27.0	123.4
Dec	85.3	21.7	63.6	26.7	21.7	5.0
Total	890.9	824.2	66.7	710.2	812.1	-101.9

Table 1b. Relationship between effective precipitations, multi-annual mean and dry year and reference evapotranspiration based on multi-annual mean of climate elements and based on the frequency of the occurrence of climate elements upon 25% precipitation probability in the western part of Istria (Poreč)

Month	Multi-annual mean (mm)		Difference	Dry year (mm)		Difference
	Effective precipitation	ETo		Effective precipitation	ETo	
Jan	49.9	21.7	28.2	24.0	24.0	0.0
Feb	49.4	30.8	18.6	27.0	28.0	-1.0
Mar	45.7	58.9	-13.2	11.7	55.8	-44.1
Apr	54.4	81.0	-26.6	33.0	75.0	-42.0
May	58.7	117.8	-59.1	113.2	93.0	20.2
June	62.3	144.0	-81.7	62.8	132.0	-69.2
July	45.1	167.4	-122.3	20.9	158.1	-137.2
Aug	65.5	148.8	-83.3	68.0	145.7	-77.7
Sep	82.8	96.0	-13.2	20.9	99.0	-78.1
Oct	83.1	55.8	27.3	69.9	62.0	7.9
Nov	91.2	33.0	58.2	136.5	30.0	106.5
Dec	64.4	24.8	39.6	30.4	15.5	14.9
Total	752.5	980.0	-227.5	618.3	918.1	-299.8

and in the western part of Istria 13.8°C. The smallest water deficit in average years in the central part of Istria was in case of olives (3.6 mm), and the highest in alfalfa (110.7 mm), while in dry years, water deficit oscillated from 43.2 mm (olives) up to 229.5 mm (alfalfa). The smallest soil water deficit in average years in the western part of Istria was again in case of olives (35.5 mm) and the highest in alfalfa (239.7 mm). In dry years, water deficit fluctuated from the smallest value 74.4 mm (in olives) up to the highest value from 288.9 mm (in alfalfa). As shown in the previously mentioned tables, a higher soil water deficit has been determined in shallow-rooted crops (tomatoes, cabbage and alfalfa) compared with deep-rooted crops (grape-vine and olives). The explanation for this is the fact that greatest changes in moisture occur in the surface layer of soil and with depth the soil contains a greater reserve of moisture and therefore plants with deeper roots face less stress during shorter dry periods. Soil water deficit affects the growth and development of field crops, which affect their yield and quality. Water deficit is especially harmful if it occurs in the "plant's critical period of water need" (Tomić, 1988; Šimunić et al., 2013). Hence, efficient agricultural production requires provision of water through adequate irrigation system to compensate the estimated water deficit for plant requirements.

Table 2a. Soil water deficit in the cultivation of crops both in average years and in dry years in the central part of Istria (Pazin)

Crop	Soil water deficit	
	Average years (mm)	Dry years (mm)
Tomatoes	63.2	191.9
Cabbage	64.5	191.2
Alfalfa	110.7	229.5
Grape-vine	16.4	105.0
Olives	3.6	43.2

Table 2b. Soil water deficit in crop cultivation both in average years and in dry years in the western part of Istria (Poreč)

Crop	Soil water deficit	
	Average years (mm)	Dry years (mm)
Tomatoes	192.7	272.4
Cabbage	188.2	242.2
Alfalfa	239.7	288.9
Grape-vine	88.0	142.5
Olives	35.5	74.4

The reaction of cultivation crops to water deficit and estimation of yield decline in average and dry years

It is well-known that any soil water deficit causes some decrease in yields, depending on the lack of precipitation and the phase of crop development. The estimation of a decline in yields both for the central and the western part of Istria has been shown in Tables 3a and 3b.

Table 3a. Estimation of decreased yields (%) in the central part of Istria (Pazin)

Crop	Estimation of a decline in yield (%)	
	Average years	Dry years
Tomatoes	18.1	34.4
Cabbage	14.3	26.9
Alfalfa	18.6	37.7
Grape-vine	4.1	13.3
Olives	1.1	10.3

Table 3b. Estimation of decreased yields (%) in the western part of Istria (Poreč)

Crop	Estimation of a decline in yield (%)	
	Average years	Dry years
Tomatoes	40.2	38.6
Cabbage	32.7	30.5
Alfalfa	33.2	40.7
Grape-vine	16.2	15.9
Olives	7.0	14.4

As evident from Table 3a and 3b there was a different decline in yields in average and dry years both between crops and between regions. Estimation of decreased yields for all the crops in average and dry years was lower in the central part of Istria compared with the western part of Istria. There is an obvious difference in yield and it is related to soil water deficit due to the fact that the yield in this case was estimated only on the basis of soil water deficit. For this reason, there is a higher yield decline in shallow-rooted crops, because in dry years there is a greater lack of moisture during the growing season in the surface (arable) layer of soil. Similar results, in terms of declining crop yields, were confirmed by Mađar et al, 1998; Šimunić et al., 2007 and 2013; Kovačević et al., 2012 and Kovačević and Josipović, 2015.

Table 4 shows crop yields for a 5-year period in the area of Istria County.

Table 4. Crop yields in the area of Istria County

Year	Total precipitation amount (mm)		Yield (t/ha)				
	Pazin	Poreč	Tomatoes	Cabbage and kale	Alfalfa	Grape	Olives
2001	791	668	9.95	12.76	4.14	7.9	1.55
2002	1355	1224	10.45	16.52	4.38	8.55	2.00
2003	852	630	7.39	7.12	3.4	7.45	1.53
2005	1072	995	16.07	19.94	4.57	10.1	2.88
2006	1032	864	17.99	18.4	4.39	8.75	2.31
Yield difference	t/ha		10.3	12.82	1.17	2.65	1.35
	%		59	64	26	26	47

In the 5-year period there is a difference in the yield of each crop. The lowest yields of all crops were in the year with the lowest annual precipitation amount (2003), while the highest crop yields were when the annual precipitation amount was around the average value (2006). In the year with the highest precipitation amount (2002), crop yields were between the value of the yield aged in the drought and the year with the average precipitation amount. Crop yield decline ranged from the largest decrease of 64% in cabbage and kale to the smallest decrease of 26% in alfalfa and vineyards. If we compare the estimated crop yield decline and the achieved results, it is evident that yield decline in the area of Istria County is higher for cabbage, tomatoes and olive crops and lower for alfalfa and grape. Considering the issue of the effect of precipitation amount upon agricultural production, it is not sufficient to be conversant solely with annual precipitation amount, but precipitation distribution during a year is also of high importance. Precipitation is just one of several abiotic factors that affect agricultural production, i.e. yield and soil with its characteristics, relief, terrain position, plant cultivar, as well as applied agrotechnics in agricultural operations play a significant role in terms of yields. The problem of yield decline can be largely solved through irrigation.

Correlation matrix is presented in Table 5. It can be noticed that there is no significant correlation between precipitation and each crop yield, which is in accordance with previously described reasons.

Table 5. Pearson's correlation matrix between annual percipitatation and yield

			Yield			
Variables	Precipitation	Tomatoes	Cabbage and kale	Alfalfa	Grape	Olives
Precipitation	**1**					
Tomatoes	0.255	**1**				
Cabbage and kale	0.582	0.864	**1**			
Alfalfa	0.565	0.758	**0.972**	**1**		
Grape	0.467	0.772	**0.891**	0.824	**1**	
Olives	0.462	0.835	0.872	0.763	**0.979**	**1**

Values in bold are different from 0 with a significance level of $P \leq 0.05$

Conclusions

Several conclusions can be reached based on the obtained results:

1. In the 30-year period in question, air temperature in the area of the central Istria increased by 0.6°C, and in the area of the western Istria by 1.6°C.
2. During the same period in the area of the central Istria the amount of precipitation increased by 187 mm, and in the area of the western Istria by 133 mm.
3. The determined soil water deficit in the central part of Istria in years with average amount of precipitation ranged from 3.6 mm (olives), up to 110.7 mm (alfalfa), while in dry years water deficit ranged from 43.2 mm (olives) up to 229.5 mm (alfalfa).
4. Soil water deficit in the western part of Istria in years with average precipitation ranged from 35.5 mm (olives) up to 239.7 mm (alfalfa). In dry years soil water deficit was within the range from 74.4 mm (olives) up to 288.9 mm (alfalfa).
5. Estimation of yield decline (%) in the central part of Istria in years with an average amount of precipitation ranged from 1.1% (olives), up to 18.6% (alfalfa), while in dry years it ranged from 10.3% up to 37.7%.
6. Estimation of yield decline (%) in the western part of Istria in the years with an average amount of precipitation ranged from 7.0% (olives), up to 40.2% (tomatoes), while in dry years it ranged from 14.4% (olives) up to 40.7% (alfalfa).
7. In the 5-year period in the area of Istria County the lowest yields of all the crops were in the year with the lowest annual precipitation amount, while the highest crop yields were when the annual precipitation amount was around the average value. In the year with the highest precipitation amount, crop yields were between the value of the yield aged in the drought and the year with the average precipitation.
8. Crop yield decline ranged from the largest decrease of 64% (cabbage and kale), to the smallest decrease of 26% (alfalfa and vineyards).
9. The problem of yield decline can be largely solved through irrigation.

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