CHANGES IN OENOCLIMATE APTITUDE INDEX CHARACTERIZING CLIMATE SUITABILITY OF ROMANIAN WINE GROWING REGIONS

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Abstract. The oenoclimate aptitude index (IAOe) reveals climate suitability for wine production in temperate climate conditions. For Romanian wine regions its values were quite stable throughout the years, indicating the possibility of practising certain types of wine production. In the last decades the IAOe values have increased. By using gridded data at 0.1 degrees resolution of temperature, precipitation and sunshine duration for the entire Romanian territory, we calculated the IAOe averages for the 1961-1990 and 1991-2013 periods for 50 wine-growing centers which are representative for the Romanian viticulture. The results indicate that the IAOe mean at Romanian viticulture area level is currently of 4629 units, 270 units higher than the ones between 1961-1990. Due to this increase, the IAOe averages for the wine-growing centers from Moldova, Muntenia, Banat, Crișana and Southern regions have passed during the recent decades to values corresponding to an upper suitability class for wine production. In the wine-growing centers from Transylvania, the IAOe maintains in the range of suitability for white table wines, while for the ones from Dobrogea and Danube Terraces the IAOe maintains in the range of suitability for quality red wines. The study provides the scientific support needed for the re-evaluation of the wine type production practiced within Romanian wine growing-centers.
Keywords: *viticulture, wine production, Transylvania Plateau, Moldavian Hills, suitability, spatial distribution*

Introduction

The study of bioclimatic indices characterizing wine regions across the globe led to the conclusion that they have been modified by climate change in the last decades (Jones et al., 2005; Duchene and Schneider, 2005; Gatto et al., 2009; Beltrando and Briche, 2010; Kryza et al., 2015). These changes are associated with changes in grapes and wine composition and characteristics (Duchene and Schneider, 2005; White et al., 2006; Laget et al., 2008; Ramos et al., 2008). Forecasts on vineyards climate predict major shifts in the distribution and structure of viticultural areas worldwide in the coming decades (Hannah et al., 2013; Moriondo et al., 2013). In this context, knowing the impact of climate change on the Romanian viticulture (fifth place in Europe as vine area and thirteenth in the world as wine production; OIV, 2016), becomes mandatory in order to develop strategies for its adaptation to climate change.

Climate change manifests globally for about 50 years by increasing temperatures and sunshine duration amid relative stability of rainfall, accompanied by aridity and intensification of weather extremes (Beniston and Tol, 1998; Karl, 1998; Fraederich et

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al., 2001; Thomas et al., 2008; Wild, 2012; IPCC, 2013). In Romania this phenomenon has been widely analysed in the literature of the past decades. The main observed developments are: significant increases in temperature and insolation during the winter, spring and summer, accompanied by constant rainfall during the year (Dumitrescu et al., 2014); significant increases in maximum and minimum temperatures during the year and unclear trends in precipitation evolution (Busuioc et al., 2015). Similar trends were observed at regional level (Piticari and Ristoiu, 2012; Planchon and Endlicher, 2014).

These climate developments has caused changes to the Romanian wine regions level as well: in the vineyards in the northern half of the country, which are cooler and specialized in white wines production, red wine grape varieties have started to be grown, while in those in the southern half, which are warmer and specialized in red wine production, musts are lacking in acidity and rich in sugar accumulations. In spite of all this evidence to which results of some recent studies can be added (Bucur and Dejeu, 2016; Irimia et al., 2017) the impact of climate change on the Romanian viticulture is still little known. Therefore, the aim of this study is to reveal the changes in climatic conditions for wine production in the Romanian wine regions as a result of climate change.

Tin order to study climate characteristics of wine growing regions, a variety of bioclimatic indices are used. Many of them are heat summation indices: Winkler Index (WI; Amerine and Winkler, 1944), Huglin Index (HI; Huglin, 1978), average growing season temperature (AvGST; Jones, 2006). Others are complex indices such as: Latitude Temperature Index (LTI; Kenny and Harrison, 1992), Composite index (CompI; Malheiro et al., 2010) or combinations of thermal and hydrologic indices (Moriondo et al., 2013). As the heat summation indices do not show the entire complexity of climatic conditions that determine the suitability for wine production (Moriondo et al., 2013), and the complex indices mentioned above were developed for climate conditions not necessarily similar to temperate climate conditions characterizing Romanian viticulture, we carried out this analysis by using the *oenoclimate aptitude index* (IAOe) which was developed in Romania by Teodorescu et al. (1987). The IAOe is highly effective in representing climate suitability for wine production in temperate climate conditions (Irimia et al., 2013, 2014). Its efficiency is given by the fact that it integrates three climatic determinants of grapes and wine quality: temperature, precipitation and sunshine duration. Due to its efficiency, in the 80s the IAOe was used to zone Romanian viticulture (Teodorescu et al., 1987), while today it is largely used to analyse vineyards climate suitability for certain wine grape assortments.

According to the research results published so far, no study has yet been carried out in Romania to reveal changes appeared in vineyards climate suitability at the national level in the last decades. Some research reveal trends in extreme weather conditions in Romanian viticulture (Bucur and Dejeu, 2016) or shifts in climate suitability for some wine regions (Irimia et al., 2017). This study aims to provide the current IAOe values revealing current climate suitability for the wine production for the 50 most important Romanian wine growing centers, spread all over the Romanian wine growing regions. The current IAOe values could offer these 50 wine growing regions the scientific support for their adaptation to the new climatic context.

The study is structured as follows: determination of spatial distribution and suitability for the wine production of the IAOe between 1961-1990 and 1991-2013; analysis of changes in the IAOe averages and suitability at the wine growing centres level; identification of causes of IAOe increases.

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Materials and methods

Study area

Romania is located between 43°37'- 48°15' N lat. and 20°15'-29° 44' E long (*Figure 1*) and has a temperate continental climate, Dfb and Dfa in Koppen-Geiger climate classification (Kottek et al., 2006). Romania's landscape is complex and diversified, with 28% represented by mountains; 42% represented by plateaus and hills; and 30% represented by plains (Bălteanu et al., 2010).

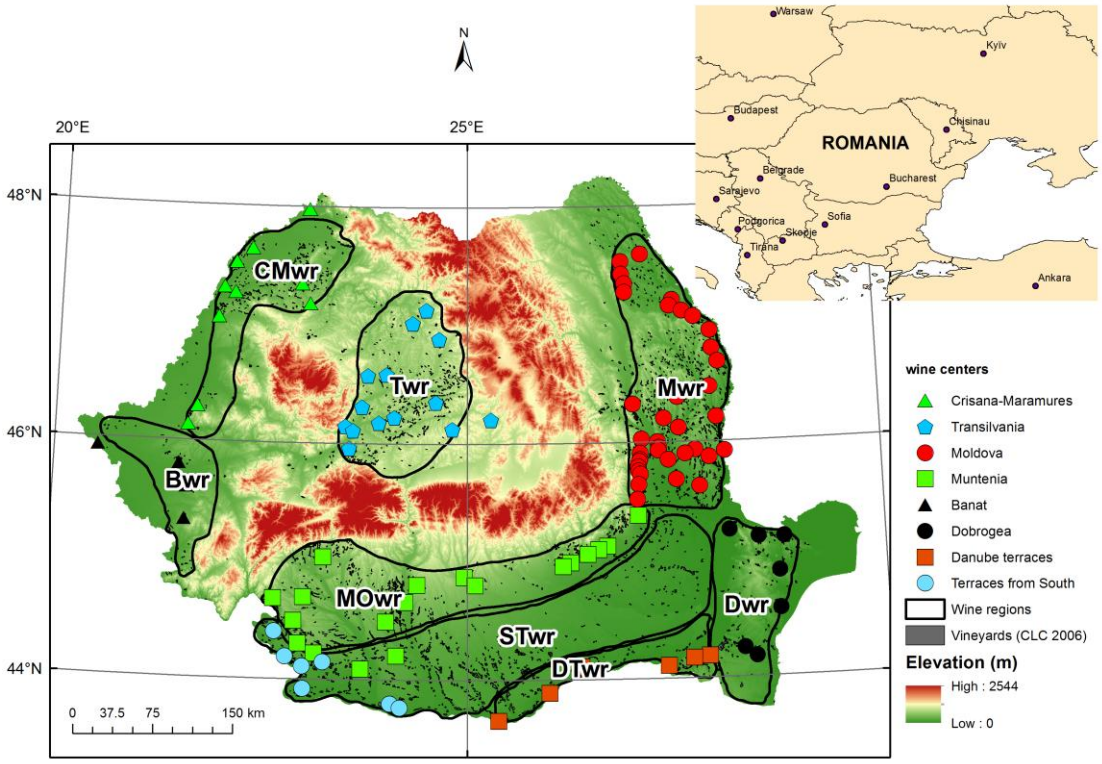

Figure 1. *Map of Romanian wine regions and wine growing centers*

As a viticulture country Romania has 197,000 ha vine plantations and produces about 6 mil Hl wine/yr (OIV, 2016). Romanian viticulture area is structured in eight large wine regions, corresponding to the historic provinces of the country. They are (*Figure 1*): Transylvanian Plateau Wine Region (Twr); Moldavian Hills Wine Region (Mwr); Muntenia and Oltenia Hills Wine Region (MOwr); Banat Hills Wine Region (Bwr); Crișana and Maramureș Hills Wine Region (CMwr); Dobrogea Hills Wine Region (Dwr); Danube Teraces Wine Region (DTwr); Sands and other suitable terrains from the South Wine Region (STwr). These eight large wine regions encompasses 141 wine growing centres (wine growing centre=vine plantations around a locality) belonging to 37 traditional wine regions. The study refers to 50 wine growing centers located in all eight large Romanian wine regions. For this study we used the map of the Romanian viticulture extracted from the Corine Land Cover Database 2006 Europe (EEA, 2006).

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Methods

The climatic data base used to calculate the IAOe values for the Romanian wine regions is represented by gridded data at 0.1 degrees resolution (10 x 10 km) of daily average temperature, annual precipitation and sunshine duration during the 1961-2013 extracted from the ROCADA database (Dumitrescu and Bîrsan, 2015). This database includes 9 climate parameters and it was achieved by interpolation of daily values recorded at meteorological stations throughout Romania by using the MISH software (Szentimrey and Bihari, 2007). The number of the meteorological stations used varies according to the climate parameter: 150 stations for air temperature, 188 stations for precipitations and 135 for sunshine duration (Dumitrescu and Bîrsan, 2015). In the first stage of the study the daily values were used to calculate the sums of active temperatures (Σta, °C/April 1st to September 30th), precipitation during the growing season (PP, mm/April 1st to September 30th) and actual sunshine duration (ASD, hour/April 1st to September 30th). In the second stage, these three parameters were used to compute the IAOe index at the same 0.1 degrees resolution (approximately 10×10 km). In the third stage the IAOe spatial data was downscaled at a finer resolution (100 x 100 m) by using the regression-kriging approach and the terrain altitude as predictor.

The IAOe is calculated for the April 1st to September 30th period according to Teodorescu et al. (1987) formula (Eq. 1):

$$IAOe = ASD + \Sigma t_a - (PP - 250) \quad \text{(Eq.1)}$$

where: ASD = actual sunshine duration (hours, April 1st to September 30th), Σt_a = sum of daily average temperatures ≥ 10 °C (April 1st to September 30th), PP = precipitation (mm, April 1st to September 30th) and 250 = minimum precipitation needed for unirrigated vines (mm). For situations where PP < 250 mm, the IAOe is computed as the sum of ASD and Σt_a (Teodorescu et al., 1987).

In Romanian wine regions the IAOe varies between 3793 and > 5200 units, with values higher than 5200 units characterizing vineyards at the southern limit of Romania (43 °lat N) which produce mainly table grapes (Oşlobeanu et al., 1991). In this study, in order to identify the changes in climate suitability for wine production of the Romanian wine regions, the IAOe is classified according to Irimia et al. (2014) as follows: IAOe < 3793= unsuitable for grapevine growing; IAOe =3793-4300= suitable for white table wines, sparkling wines, wines for distillates (WTW+SW+WD); IAOe=4301-4600=suitable for quality white wines and red table wines (QWW+RTW); IAOe > 4600 = suitabile for quality red wines (QRW).

Results

Spatial distribution and the suitability for wine production of the IAOe between 1961 and 1990

The spatial distribution of the IAOe between 1961 and 1990 reflects the already known base climate suitability of Romanian wine regions, attested by their specific types of wine production (*Figure 2*): climate suitability for red quality wine in the southern half of the country where the STwr, DTwr, Dwr and MOwr are located; and climate suitability for white wines in the northern half of the country where Mwr, Twr, Bwr and CMwr are located.

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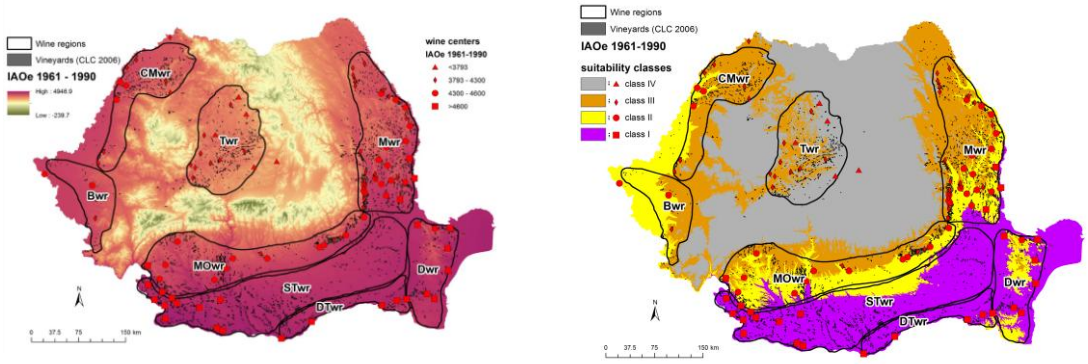

a. b.

Figure 2. *Spatial distribution of IAOe in Romania during the 1961 to 1990 time period and location of the main Romanian wine producing centers: a. continuous values; b. classified values. Values were calculated based on gridded data at 0.1 degree resolution of temperature, precipitation and sunshine duration extracted from ROCADA data base (Dumitrescu and Bârsan, 2015) and classified according to Irimia et al. (2014)*

Statistics for the spatial distribution of the IAOe across the Romanian wine regions (*Table 1*) show that between 1961-1990 its averages were between 3513 and 4647 units, with an average of about 4359 units indicating the prevailing climate suitability for QWW and RTW. The warmest wine regions and the most suitable for red wines are Dwr, DTwr and STwr where the IAOe averages exceed 4600 units (suitability for QRW); for all northern wine regions - Mwr, Twr, Bwr and CMwr - the IAOe averages are bellow 4300 units revealing suitability for white wine production (WTW, SW, WD); the IAOe for the MOwr, located at the transition zone between the southern and northern of Romania, has an average of 4300 units revealing suitability for QWW and RTW. IAOe Max reveals temporal variability of climate suitability of the wine regions specialized in white wine production, which in a number of years manage to produce even QRW. An exception is the Twr where the IAOe Max (4147 units) reveals the total lack of suitability for red wine production during the 1961 to 1990.

Table 1. *Statistics for the IAOe spatial distribution within Romanian wine regions during the 1961 to 1990 and during the 1991 to 2013*

Wine region	**Surface**	**Statistical parameters IAOe 1961-1990**				
	(Mln ha)	Min	Max	Range	Mean	STD
Twr	1,489	2815,3	4147	1332	3798,3	182,6
Mwr	1,949	2863,3	4714,3	1851	4249,0	222,1
MOwr	2,069	3041,5	4814	1772,5	4345,3	197,5
Bwr	0,726	3477,7	4471	993,3	4275,2	146,4
CMwr	1,121	3089,5	4383,4	1293,9	4134,8	168
Dwr	0,993	3870,9	4829,3	958,3	4625,1	130,7
DTwr	0,542	4480,7	4884,9	404,2	4736,4	62,5
STwr	2,933	4469,7	4937	467,3	4708,4	91,8
Average	**-**	**3513**	**4647**	**1134**	**4359**	**150**
		Statistical parameters IAOe 1991-2013				
Twr	1,489	3039.8	4447.6	1407.9	4011.9	186.3
Mwr	1,949	3132.3	5004.3	1871.9	4537.2	223.5
MOwr	2,069	3313.8	5071.6	1757.8	4599.2	204.1
Bwr	0,726	3761.3	4775.7	1014.4	4561.1	148.4

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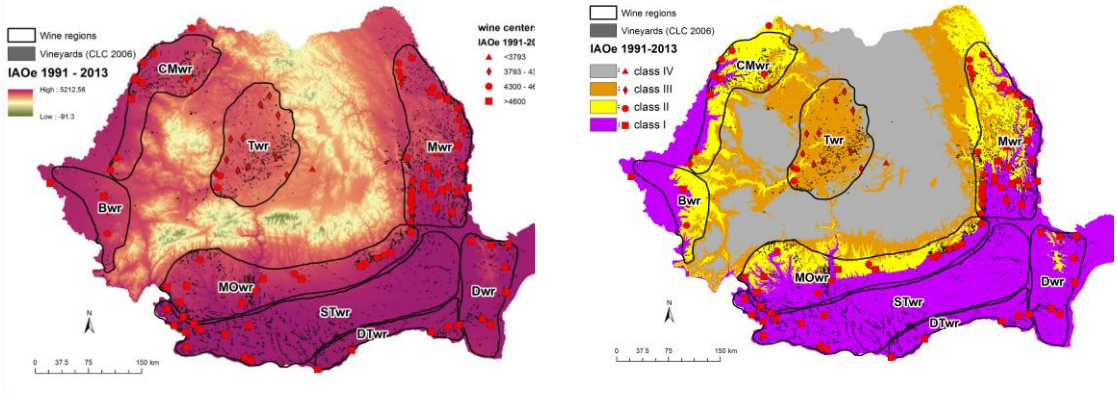
CMwr	1,121	3371.5	4702.5	1331.0	4446.4	169.1
Dwr	0,993	4125.8	5106.6	980.8	4896.6	137.2
DTwr	0,542	4761.5	5144.9	383.5	5005.6	60.2
STwr	2,933	4722.6	5203.1	480.5	4978.3	89.3
Average	-	**3778**	**4932**	**1153**	**4629**	**152**

Spatial distribution and suitability of the IAOe for wine production between 1991 and 2013

The spatial distribution of the IAOe between the 1991 to 2013 reveals major changes in climate suitability for wine production in Romanian wine regions (*Figure 3*): the area with IAOe exceeding 4600 units extended towards the northern half of Romania, within the area of Mwr, Bwr and CMwr while the southern wine regions are almost entirely covered by climate suitability for red quality wine production.



a. b.

Figure 3. *Spatial distribution of IAOe in Romania during the 1991 to 2013 time period: a. continuous values; b. classified values. IAOe values were calculated based on gridded data at 0.1 degree resolution of temperature, precipitation and sunshine duration extracted from ROCADA data base (Dumitrescu and Bârsan, 2015) and classified according to Irimia et al. (2014)*

Statistics for the spatial distribution of the IAOe between the 1991 to 2013 (*Table 1*) show that its mean for the Romanian wine regions increased during this time period by 270 units to 4629 units today. The current average reveals the predominance in Romania of climate suitability mainly for QRW and QWW in secondary. The IAO mean for the southern wine regions - STwr, DTwr and Dwr - remain suitable for QRW but it approaches by 5,000 units, value that characterize vineyards producing mainly table grapes. As a result of these increases in the wine regions from the northern half of Romania (Bwr, CMwr, Mwr) except the Twr, the IAOe exceeded between the 1991-2013 the threshold of 4300 units that indicates the suitability for QWW and RTW. Within the Twr, the coolest wine region of Romania, IAOe increased by 231 units but still lies in the range of suitability for WTW.

Changes in IAOe averages and suitability at the wine growing centers level

The data in *Table 2* shows that between 1961 and 2013, the IAOe mean increased by 236-346 units within Romanian wine growing centers. This increase causes major changes in climate suitability for wine production: except the wine centers from Twr,

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Dwr, TDwr and STwr, which still lie in the initial climate suitability class, the climate suitability of all the other wine growing centers from Romania passed to the upper suitability class: from class III to class II, and from class II to class I (*Table 2*). Although the IAOe average increased for each wine center in Twr, they still stands in the range of climate suitability for WTW, SW and WD. It is noteworthy here the obtaining of climate suitability for WTW, SW, WD by Bistrița, Batoş, Triteni and Apold wine growing centers of Twr, whose IAOe means during the 1961-1990 were below the threshold of suitability for WTW, SW and WD. In the case of southern wine centers of Romania (Dwr, TDwr and STwr) characterized even 1961 to 1990 by suitability for QRW, the IAOe average increased during the 1991 to 2013 to 5,000 units, a value specific to areas producing mainly table grapes.

The IAOe largest increase (346 units) during the 1991 to 2013 at Romania wine growing centers level is recorded for Lechința from Twr (*Table 2*) while at regional level for the W and NW of the country, within Teremia (+304 units), Măderat (+298 units), Diosig (+315 units), Şimleul Silvaniei (+315 units), Oradea (+323 units) and Zalău (+315 units) wine growing centers. IAOe important increases exceeding 300 units were recorded also within some wine growing centers from the central part of Mwr: Copou Iaşi (+303 units), Bucium (+312 units), Comarna (+320) and Murgeni (+312 units) are a few examples. IAOe increases have led to changes in climatic suitability for wine production in the affected areas.

The smallest IAOe increase at the country level (+238 units) is recorded in the Ștefăneşti wine growing center. However, the entire MOwr to which the Ștefănești wine growing centre belongs, is characterized by a low increase in IAOe average, of about +254 units. But in spite of these small increases many of the MOwr wine growing centers acquire climate suitability for QRW between 1991-2013 (*Table 2*).

Causes of IAOe increase

As shown in *Table 2* the cause of IAOe increase between the 1991 to 2013 is mainly the increase of active temperatures and of sunshine duration.

However, the largest increases in IAOe average recorded in Bistrița and Lechinţa wine growing centers from Twr and in certain wine growing centers from Mwr (Bucium, Comarna, Uricani, Copou, Vutcani) is caused by the increase of active temperatures and sunshine duration associated with a decrease of precipitation average. For the biggest part of Romanian wine growing centers, the IAOe increase is due exclusively to the increase of temperatures and insolation, while the precipitation amount is relatively unchanged.

The largest increase in the sum of active temperature during the 1991-2013 is recorded in the wine growing centers from Bwr and CMwr. It varies between +202...+221°C with an average of 212.5°C, as compared to +173…+216°C and an average of 193.78°C for the rest of Romanian wine growing centers. Significant increases in the sum of active temperatures impacting the IAOe averages are also recorded in some isolated wine growing centers as Bistrița and Lechinţa (+216 °C for both of them) from Twr; and also in some wine growing centers from the southern of Mwr (Tecuci, Iveşti, Corod) where the increase of the sum of active temperatures exceeded 200 °C.

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Table 2. *Averages and differences for the oenoclimate aptitude index (IAOe), sum of active temperatures (Σt_a), precipitations during growing season (PP), and actual sunshine duration (ASD) for some Romanian wine centres, during the 1961-1990 and 1991-2013 time periods. Values were calculated based on gridded data at 0.1 degree resolution (10 × 10 km) of temperature, precipitation and sunshine duration extracted from ROCADA data base (Dumitrescu and Bârsan, 2015)*

Wine region	Wine growing center	IAOe/wine growing center (units)			Σt_a (°C)		PP (mm)		ASD (hours)	
		1961-1990	1991-2013	±	1961-1990	1991-2013	1961-1990	1991-2013	1961-1990	1991-2013
Twr	Bistrita	3689	4035	+346	2404	2620	420	396	1317	1423
	Lechinta	3892	4221	+329	2673	2889	409	398	1317	1419
	Batoş	3640	3956	+316	2580	2779	414	417	1321	1435
	Zagar	3866	4160	+294	2651	2841	416	430	1341	1444
	Jidvei	3983	4269	+286	2806	3000	400	417	1310	1427
	Sebeş	4034	4312	+278	2853	3058	395	412	1289	1368
	Apold	3680	3941	+261	2286	2465	437	436	1329	1414
Mwr	Hlipiceni	4218	4519	+301	2895	3093	388	388	1376	1480
	Cucuteni	3965	4230	+265	2716	2897	386	400	1353	1446
	Bohotin	4346	4653	+307	2981	3174	339	331	1430	1540
	Averesti	4155	4459	+304	2753	2929	339	335	1427	1537
	Husi	4436	4741	+305	2796	2971	322	322	1502	1617
	Nicoresti	4390	4677	+287	2968	3165	344	345	1447	1540
	Buciumeni	4274	4572	+298	2968	3165	351	350	1442	1535
	Panciu	4108	4397	+289	2932	3128	399	398	1376	1471
	Jaristea	4283	4567	+284	3074	3274	395	397	1362	1447
	Odobesti	4333	4614	+281	3074	3274	395	397	1362	1447
	Pechea	4602	4877	+275	3125	3320	302	312	1438	1517
	Cotesti	4244	4519	+275	3103	3302	395	397	1362	1447
MOwr	R. Sarat	4416	4690	+274	3151	3340	357	366	1420	1516
	Merei	4471	4753	+282	3202	3391	373	386	1427	1497
	Pietroasele	4066	4338	+272	3106	3294	373	386	1427	1497
	Tohani	4156	4401	+245	3200	3391	358	372	1407	1484
	Urlati	4398	4634	+236	2938	3128	385	396	1334	1400
	Topoloveni	4364	4604	+240	3004	3195	393	411	1464	1542
	Samburesti	4394	4646	+252	2919	3100	412	414	1466	1549
	Dragasani	4560	4819	+259	3172	3355	383	385	1462	1537
	Iancu Jianu	4595	4851	+256	3119	3306	358	365	1481	1558
	Segarcea	4767	5023	+256	3252	3435	310	321	1555	1642
Bwr	Teremia	4471	4775	+304	3110	3331	322	325	1440	1528
	Recas	4339	4626	+287	3041	3253	361	359	1408	1482
	Silagiu	4234	4524	+290	2971	3179	395	376	1414	1483
	Tirol	4276	4546	+270	2952	3154	413	415	1411	1484
CMwr	Halmeu	4172	4468	+296	2873	3084	392	409	1424	1527
	Valea lui Mihai	4288	4586	+298	2962	3170	346	365	1445	1544
	Diosig	4365	4671	+306	3018	3228	342	361	1451	1550
	Oradea	4334	4657	+323	2955	3167	338	335	1455	1550
	Saniob	4356	4671	+315	2949	3163	354	357	1436	1534
	Samsud	4099	4414	+315	2720	2938	395	403	1376	1483
	Maderat	4286	4598	+312	2968	3181	367	376	1459	1557
	Minis	4288	4573	+285	2988	3206	367	382	1441	1532
Dwr	Macin	4637	4913	+276	3203	3399	267	281	1513	1599
	Babadag	4747	5016	+269	3186	3382	212	224	1556	1650
	Murfatlar	4757	5025	+268	3145	3360	218	257	1534	1623
TDwr	Aliman	4792	5069	+277	3264	3464	260	290	1533	1648
	Oltina	4792	5064	+272	3232	3421	271	304	1544	1650
	Ostrov	4746	5010	+264	3220	3415	286	313	1515	1618
	Greaca	4668	4933	+265	3250	3450	329	340	1507	1586
STwr	Jiana	4716	5003	+287	3291	3481	313	314	1539	1633
	Dăbuleni	4853	5102	+249	3362	3535	295	301	1536	1617

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Precipitation during the growing season (PP) at Romanian wine growing centres level presents a relative stability (*Table 2*), with insignificant increases of about +1...+10 mm between the 1991 and 2013. Exceptions are the wine growing centers from Dwr where the average of PP during the 1991-2013 highly increases with values from +15 mm to + 39 mm. Increases of +16 mm to +30 mm of the PP are also recorded in the wine growing centers from Twr, in some wine growing centers from the eastern limit of MOwr (+15 mm...+20 mm), and in some wine growing centers from the northern half of CMwr (Halmeu Sanislău, Valea lui Mihai, Diosig). Conversely, the decrease in PP average between the 1991-2013 time period, ranging from -13 mm to -21 mm, are recorded in the wine growing centers from the central part of Mwr (Bucium, Uricani, Comarna, Copou) and in Bistrița and Lechința wine growing centers from the northern limit of Twr (-11 mm and -24 mm respectively.

The average of the sunshine duration (ASD) for the 1991-2013 time period increased by 60 to 180 hours for all wine growing centers from Romania. The highest values, higher than 100 hours, are recorded in the wine growing centers from Twr; in those within the northern half of Mwr; within the northern half of CMwr; and at the southern limit of Dwr (*Table 2*).

Discussion

By using spatial data of temperature, sunshine duration and precipitation for the entire Romanian territory at 0.1 degrees resolution (10×10 km), our study managed to provide the current IAOe averages for the most important 50 Romanian wine growing centers. The current IAOe averages reveal the current climate suitability for wine production of the wine growing centers, as it looks like after the climate change influence during the last two decades. Changes of the IAOe averages revealed by this study fall into developments of bioclimatic viticulture indices averages recorded at global and regional levels (Ramos et al., 2008; Laget et al., 2008; Duchene and Schneider, 2010), in the sense of increasing vineyards climate heliothermal resources amid diminishing water resources.

The general result of the study it the increase by 270 units of the IAOe average at Romanian wine growing regions level, from 4359 units between 1961-1990 to 4629 units between the 1991-2013. This increase shows the transition of the IAOe average for Romania viticulture from a range defining climate suitability for QWW (4300-4600 units) between 1991-2013 to a range defining the suitability for QRW (>4600 units) at present. The new values of IAOe calculated for the 1961 to 1990 are consistent with those reported for Romanian wine regions and wine growing centers by Teodorescu et al. (1987) and Oşlobeanu et al. (1991). They reflect accurately the traditional types of wine production specific to those areas: WTW, SW, DW, QWW in Twr, Mwr, CMwr and Bwr; RTW and QRW in Dwr, DTwr and STwr; QWW and QRW in MOwr located at the transition zone between the southern half and the northern half of Romania. Climate suitability evolution towards red wine production revealed by the current IAOe averages is consistent with that predicted by Mesterházy et al. (2014) and Stock et al. (2005) for temperate continental climate conditions in Europe. IAOe variability within Romanian wine growing regions maintains within the original range, although the higher frequency and levels of climatic extremes registered during the last decades (Bojariu et al., 2015), are able to influence the quality characteristics of grapes and wine production.

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IAOe averages for the 50 wine growing centers analysed in this study reveal the spatial variability of climate suitability within Romanian viticulture areas. They show the different abilities of wine growing centers to adapt to climate change, despite the overall environmental characteristics of the larger area they belong to. For example, the difference in the IAOe average for the contiguous Lechinţa and Batoş wine growing centers from the northern part of Twr is around 300 units. The same for the Sebes and Apold wine growing centers from Twr; for the Urlați and Tohani from MOwr; for the Silagiu and Recaş of Bwr; for the Valea lui Mihai and Diosig from CMwr. In all these cases, the wine growing center with a lower IAOe average is located at a higher and cooler altitude, which indicates larger possibilities for its adaptation to climate change. Assessed according to the latitudinal distribution the IAOe variability is found to diminish from the northern half, where all types of wine production can be obtained, to the southern half where suitability for QRW predominates.

One of the most important results of our study is the revealing of the changes in temperature, precipitation and sunshine duration for the wine growing centers from Romania. IAOe increases is caused by the rising temperatures and insolation, against the relative stability of precipitation. The results of our study regarding the distribution of temperature increases, sunshine duration and precipitation diminishing are consistent with those characterizing the particularities of climate change across the Romanian territory (Dumitrescu et al., 2014; Piticari and Ristoiu, 2012; Sfâcă, 2015).

Our study demonstrates once again that wine types production is determined by well defined climate suitability ranges specific to restraint areas, as is the case of the analysed wine growing centers. These ranges of climate suitability remained quite stable over time and allowed the establishing of the representative wine grape assortments and wine types for the vineyards. Changing the boundaries of these climate suitability ranges as an effect of climate change involves changing the types of wine production and wine grape assortments of vineyards. Today, the cool climate vineyards within traditional areas of vine culture have larger possibilities of adaptation to climate change, mainly to rising temperatures. On the other hand, as earlier research revealed (Jones et al., 2005) wine regions in warmer climate, in Romania's case southern wine regions (Dwr, DTwr and STwr), will face exceedings of climate suitability ranges for quality wine production. This will force them either to change their specific type of wine production by replacing their traditional wine grape variety assortments or to implement adaptation measures to climate change (Keller, 2010).

This study offers a scientifically based support to assess the impact of climate change on Romanian wine growing centers climate and to outline strategies of their adaptation to this phenomenon. Obtaining accurate depictions than those provided by this climate based study requires fine-scale analysis also of vineyards topography and soils, which can be achieved by using methodologies adapted to temperate continental climate characterizing Romania (Irimia et al., 2013, 2014).

Conclusions

By using the daily averages of temperature, precipitation and sunshine duration for the 1961 to 2013 time period at a 0.1 degrees resolution (10×10 km), our study provides averages for the 1961 to 1990 and for the 1991 to 2013 of the oenoclimate aptitude index IAOe for Romanian wine regions. The comparative study of the averages and the spatial distribution of the IAOe between the two time periods highlights major changes

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in climatic suitability for wine production in the last five decades in all wine growing centers of Romania. Except for the wine centres from Transylvania (Twr), in all wine growing centers the average of the IAOe moved during the 1991 to 2013 to the upper suitability class as compared to 1961-1990. Current IAOe averages reveal an improvement of climate suitability for the wine production in wine growing centers of Romania and the occurrence of climatic conditions to diversify the types of wine production. The study highlighted the negative evolution of climate suitability for wine production within the wine growing centers from the extreme south of Romania, where the current climate becomes more and more suitable for table grapes production. Further studies on the development of chemical composition and on the sensory profile of grapes and wines produced in this wine centers will clear up the way of these developments in the coming years.

The changes in climate suitability revealed by this study are likely to generate changes in wine grape assortments and traditional types of wine production of Romanian wine growing regions. Changes in wine grape assortments argued as adaptation to climate change are happening nowadays in Romania viticulture areas, but they are not integrated in a national strategy based on scientific support, but more on intuition of local wine producers and on their wish to diversify the wine types production. Our study provides the necessary support to outline such a national strategy and also to guide policy makers and wine growers in their work on adaptation of viticulture to climate change.

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