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ORIGINAL ARTICLE

Modelling of the formation of grapevine yield in Ukraine under climate change scenarios A1B and A2 until 2050 (on example of grapevine varieties Zagrey and Rubin tairovskyi)

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Aim: Evaluate the possible change in agroclimatic resources and the resulting grape yield in the Forest-steppe and Steppe zones of Ukraine until 2050 under the impact of climate change.

Methods: The trend in global and regional climate requires a revision of crop placement in the country. One of the possible solutions is evaluation of agroclimatic resources according to different scenarios of climate change.

Results: The article presents the results of actual studies in possible changes of agroclimatic resources until 2050 under scenarios of climate change A1B and A2 and the conditions for the formation of grapevine yield of medium-ripening variety (Zagrey) and late-ripening variety (Rubin tairovskyi) using the dynamic modeling method. The calculations were performed based on meteorological stations data of Ukrainian hydrometeorological network, located in the Forest-steppe and Steppe zones.

Conclusion: Shift features of the grape phenological stages, temperature and rainfalls, indicators of photosynthetic activity and productivity of grape in the natural zones of Ukraine until 2030 and 2050 under two climate change scenarios compared to the base period (1986-2005) were estimated.

Keywords: Grapevine, Yield, Modeling, Climate change scenarios A1B and A2, Natural zones of Ukraine, 2030-2050.

Introduction

The impact of climate change on the growth, development and formation of crop productivity is an obvious fact. Climatologists have identified a trend of global warming, which manifests itself in rising air temperatures and decreasing precipitation. It is noted that the nature and intensity of climate change may vary depending on the region. For the agricultural sector, established trends in climate change require a review of the management strategy, first of all, changes in the location of crops, their variety and species composition, and new technologies. Research in this area is relevant and has theoretical and practical significance for Ukrainian viticulture. Fundamental studies of the impact of agroclimatic conditions on the growth, development and formation of grapevine yield have been conducted since the middle of the twentieth century. Approaches and methods to evaluate the impact of different components of agroclimatic resources on the quantitative and qualitative characteristics of grape productivity were proposed preiovusly by several researchers (Davitaia F., Amirdzhanov A., Turmanidze T., Fursa D.).

Different physical and statistical modeling methods were developed for solving the problem of assessing the agrometeorological impact on the condition and formation of grape yields. These methods were based on the parallel analysis from long-term data of agrometeorological observations of grapes (dates of phenological stages, elements of yield structure) and meteorological observations. Several agrometeorological indicators are proposed and regression models are developed, which allow determining the indicators of vine condition and grape yield, in case of adapting them to specific territories with their natural conditions. These models have been used for a long time for long-term forecasting of the vine condition and the yield and estimates of the agroclimatic resources of the vineyards' territory. There are many positive moments of the application of physical and statistical methods, but there is one drawback in the inability to take into account adverse agrometeorological conditions within certain phenological stages of the vine (interphase periods).

The use of mathematical dynamic models makes it possible to overcome this disadvantage. The basis for using of these models was laid in the research of de Wit C.T. (Monsi and Saeki, 1953). The method of dynamic modeling has been widely used in determining the agrometeorological impact on the vine condition and productivity of most agricultural crops (Sirotenko O.D., Polovyj A.M., Dmitrenko V.P.). The advantage of this method is to take into account the temperature, light, and precipitation in ten-day period or diurnal terms.

The first studies to determine the impact of climate change on agricultural production were conducted in 1970-1980. In the last two decades, the impact of assessment of the climate change impact on vine conditions and the formation of agricultural crop productivity is studied under climate change scenarios *A1B, A2, RCP4.5, RCP8.5, RCP2.6,* and *RCP6.0*. The first two scenarios consider climate change under the influence of generalizing factors of the technologies development of the industries and anthropogenic pressure on the environment. The other four scenarios take into account the concentration of CO_2 in the geosphere due to factors in the pace of production technologies development.

For most agricultural crops in Ukraine, the impact of climate change was studied at Odessa State Ecological University (Stepanenko et al., 2015). Scientists have studied the impact of climate change on viticulture and winemaking in different countries in the last 15-20 years. The change in temperature during the vine growing season in traditional viticulture countries

(France, Italy, Spain, Austria, Germany) was determined using physical and statistical models and different scenarios of climate change (Bindi et al., 1996; de Orduna, 2010; Jones and Webb, 2010; Romero et al., 2016; Sirnik et al., 2018).
The shift of the beginning of development ("sap movement") and other phenological stages to earlier dates was established, as well as acceleration of the rate of development and formation of grapes due to the temperature increase of 1.8-2.5°C. Due to this rate of development, the quality of biophysical and physiological processes is far from optimal, leading to the vine deterioration, reducing grape yield and the quality of grape products.
There are some differences in the results (Bindi et al., 1996; de Cortázar-Atauri, 2006; Cahill et al., 2007; Lobell et al., 2006; Santos et al., 2011). Most scientists claim that the climatic conditions for viticulture are deteriorating. At the same time, for example, the results of ensemble modeling in the A1B climate change scenario indicate that climate change can significantly contribute to the wine industry in the Douro Valley (Portugal). Thus, by 2050 there is a slight tendency to increase yields, followed by rapid and continuous growth of yields by the end of the XXI century, on average, by 800 kg/ha (Santos et al., 2011). The impact of climate change on grape yield in California has been assessed. Using several statistical models of yield formation and various climate change scenarios (Lobell et al., 2006), it was found that grape yields are likely to decline by 2050 and by the end of the century by 5%.
The purpose of the presented research is to evaluate the possible agroclimatic changes and the resulting grapevine production in the Forest-steppe and Steppe zones of Ukraine until 2050 under climate change conditions.

Materials and Methods

To date, industrial vineyards are located mainly in the Steppe zone (Middle steppe and Southern steppe subzones-Odesa, Mykolaiv, and Kherson oblasts) and in Zakarpattia. Specific viticulture centers are found in the Zaporizhzhia, Kirovograd, and Vinnytsia oblasts. Due to the increase in temperature, it is possible to significantly change the vineyards area in the northern regions and in the traditional vine growing area. Research in this direction has been conducted since 2012 in the NSC "V.Ye. Tairov IVW" (Odesa, Ukraine). A dynamic model of the formation of grape productivity "Vitis vinifera-2013" was developed by Lyashenko and Zhygailo (2012), which has a block structure (4 blocks). The input block contains general data on the geographical location of the study plots, agrobiological characteristics of vines, and meteorological data that characterize the mode of light, temperature, and precipitation. The second block presents the parameters determined from the literature and the results of a field experiment conducted in 2012-2013 on grapes of medium-ripening variety (Zagrey) and late-ripening variety (Rubin tairovskyi) in the collection area of Tairov Institute (Middle steppe subzone of the Steppe zone of Ukraine). The third block contains a system of differential equations describing the vine photosynthetic activity and consists of subblocks of plant photosynthesis and respiration. The fourth calculation block describes the results of modeling photosynthetic activity (ten-day period formation of leaf surface area, photosynthetic potential, total plant biomass and grape yield). Verification of the model showed good validity, the error in the grape yield under different types of agrometeorological conditions (wet, arid, medium) did not exceed 14-16% (Lyashenko, Zhygailo, 2012).
The modeling of agroclimatic change according to 9 meteorological stations located in the Odesa, Mykolaiv, and Kherson oblasts (data from agroclimatic directories in these oblasts) which characterize conditions of the Forest-steppe and Steppe zones was carried out and presented in the article. Changes in the values of the agroclimatic parameters of light, temperature, and precipitation during the period of development from budburst to harvest (technical maturity) of the grapevine varieties Zagrey and Rubin tairovskyi were studied and presented.

Results and Discussion

The modeling results showed the difference in the influence of climatic conditions on photosynthetic activity and the productivity formation of two grapevine varieties in the Forest-steppe and Steppe zones (Northern steppe and Sothern steppe subzones) under climate change scenarios A1B and A2. The phenological stages of grape development in 2011-2030 will be observed 2-4 (Zagrey) and 2-6 (Rubin tairovskyi) days earlier than the average dates for 1986-2005 under the A2 scenario in the Southern steppe. The growing season can be reduced by 2 days for Zagrey and by 10 days for Rubin tairovskyi. In 2031-2050 the rate of grape development will be hastened, all phenological stages will be observed 5-7 days earlier than in the base period for Zagrey and 5-13 days earlier for Rubin tairovskyi. The duration of the growing season will be reduced by 7 and 8 days, respectively, for both varieties. Therefore, a more significant difference between the onset of stages and the duration of the growing season will be observed for Rubin tairovskyi. The acceleration of grape development is observed under the A1B scenario more than under the A2 scenario, the onset of phenological stages occurs earlier. This acceleration in the dates of bud burst and flowering in 2011-2030 is 3-10 (Zagrey) and up to 14 days (Rubin tairovskyi), 7 and 10 days in the dates of harvest (Zagrey and Rubin tairovskyi, respectively) in the Southern steppe subzone. In 2031-2050, the shift of the dates of stages onset has the same trend and is 7-12 (Zagrey) and almost 20 days (Rubin tairovskyi).
Similar calculations were done by using a model for the Northern steppe and Forest-steppe. There is a general trend of shifting stages to earlier dates and the general reduction of the growing season in 2011-2030 (Zagrey) and in 2031-2050 (Rubin tairovskyi) under the A1B scenario. The difference in average temperature and precipitation during the growing season of Zagrey and Rubin tairovskyi in the Southern and Northern steppe, and the Forest-steppe were found according to the modeling of agroclimatic conditions under scenarios A1B and A2 in the period 2011-2030 and 2031-2050 compared to the base period (1986-2005). The results of the modeling of the agroclimatic conditions in the Southern steppe are presented in Table 1. The largest change in agroclimatic resources is observed under the A1B scenario in 2031-2050 during the growing season of Rubin tairovskyi.
In the Northern steppe and Forest-steppe changes in indexes values are slightly lower. It was found that the agroclimatic conditions of the northern regions do not carry such risks of deterioration of the precipitation of the vine growing season, especially for Rubin tairovskyi.

Table 1. Agroclimatic conditions of the vine growing season in the Southern steppe.

Scenario	Period	Phenological period							
		Bud burst-Flowering		Flowering-Veraison		Veraison-Harvest		Bud burst-Harvest	
		Precipitation (mm)	Average air T, °C	Precipitation (mm)	Aver. air T, °C	Precipitation (mm)	Aver. air T, °C	Precipitation (mm)	Aver. air T, °C
					Zagrey				
	86-05	50	14.9	99	21.1	95	21.3	244	19.5
A2	11-30	50	14.5	64	20.7	47	21.6	172	19.3
	Difference	0	-0.4	-35	-0.4	-48	+0.3	-72	-0.2
	31-50	43	15.1	58	21.0	38	22.1	140	19.9
	Difference	-7	+0.2	-41	-0.1	-57	+0.8	-104	+0.4
A1B	11-30	44	15.4	69	21.9	47	24.2	160	20.9
	Difference	-6	+0.6	-30	+0.9	-48	+2.9	-84	+1.7
	31-50	47	15.2	65	21.5	51	24.3	159	20.8
	Difference	-3	+0.3	-34	+0.4	-44	+3.0	-85	+1.3
					Rubin tairovskyi				
	86-05	56	15.7	101	21.7	95	20.0	252	19.4
A2	11-30	51	15.5	59	21.4	56	20.4	174	19.4
	Difference	-5	-0.2	-42	-0.3	-39	+0.4	-78	0.0
	31-50	39	15.7	61	21.4	37	21.7	137	20.1
	Difference	-17	0.0	-40	-0.3	-58	+1.7	-115	+0.7
A1B	11-30	50	16.3	70.0	22.6	46	23.7	166	21.2
	Difference	-6	+0.8	-31	+1.2	-49	+3.7	-86	-1.8
	31-50	42.8	15.8	69.9	22.2	46	24.0	163	21.0
	Difference	-8.6	+0.1	-30.7	+0.8	49	+4.0	-89	+1.6

Subsequently, the simulation of vine photosynthetic activity during the vine growing season was presented for these grapevine varieties in terms of 3 intervals: 1986-2005, 2011-2030, and 2031-2050. The dynamics of the leaf surface area and raw biomass of different parts of the bush and integral indicators (photosynthetic potential, total bush biomass, and yield) were determined.

The general tendency to decrease leaf surface area and general bush biomass for both varieties in the periods 2011 to 2030 and 2031 to 2050 was established. Moreover, in both scenarios in the period from 2011 to 2030 the difference in leaf area, compared to the base period, is greater than in the period from 2031 to 2050. There is also a tendency to reduce the difference of leaf surface area from south to north, and Rubin tairovskyi compared to Zagrey.

The difference in the dynamics of leaf surface area formation in Ukrainian natural zones was revealed. In the Southern steppe in 2011-2030 and 2031-2050, the leaf surface area on the date of maximum growth will be much smaller than in 1986-2005. And the date of maximum growth will be 10 days earlier. The maximum leaf surface area is slightly larger in absolute value in the Northern steppe at similar dynamics of leaf surface formation, and in the Forest-steppe the intensity of leaf apparatus formation is close to the intensity in the Southern steppe.

There is also a difference in the formation of the leaf surface in natural zones according to scenarios of climate change. For example, the maximum leaf area in the Southern steppe under the A1B scenario in 2011-2030 will decrease compared to the base period from 10.6 to 8.2 m^2/bush, which is less than under the A2 scenario for Rubin tairovskyi. In the Northern steppe, the maximum leaf area increases from 10.2 to 10.9 m^2/bush, and in the Forest-steppe decreases from 10.5 to 10.1 m^2/bush. In 2031-2050, the maximum leaf area in the Southern steppe and the Forest-steppe decreases from 10.6 to 7.3 and from 10.5 to 9.7 m^2/bush, respectively.

The analysis of results of modeling the accumulation of bush biomass during the vine growing season was conducted. For example, the dynamics of the total biomass of Rubin tairovskyi in natural zones under the A1B scenario is presented (Fig. 1).

It is clear that the accumulation of total bush biomass in 2011-2030 and 2031-2050 will be less than in the base period (1986-2005). The most significant decrease will be observed in the Southern steppe.

Total biomass increases slightly in the Northern steppe in 2011-2030, and is almost the same index in 2011-2030 and 2031-2050 in the Forest-steppe. Total biomass in the technical maturity stage will decrease from 3060 to 2679 g/bush (Southern steppe), from 2737 to 2431 g/bush (Northern steppe), and from 2845 to 2320 g/bush (Forest-steppe) in 2011-2030. This index will decrease in the Southern steppe and Forest-steppe, and increase in the Northern steppe in 2031-2050.

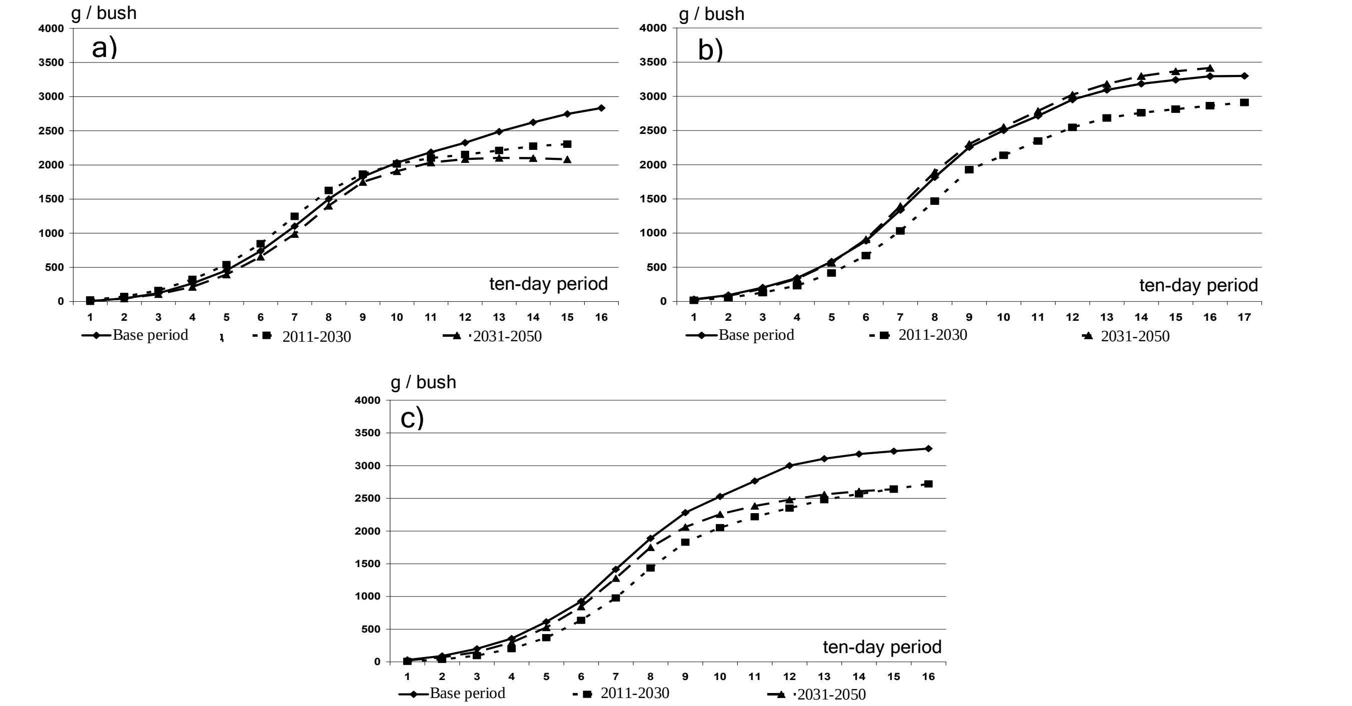

Fig. 1. Dynamics of the total biomass of Rubin tairovskyi under the A1B scenario. a) Southern steppe, and b) Northern steppe, c) Forest-steppe.

Generalized integrated indicators of the photosynthetic activity (including yield) of Zagrey under the A2 scenario are presented in Table 2. The photosynthetic potential to the stage of technical maturity (harvest) for the period 2011 to 2030 in the Southern and Northern steppes, respectively, will decrease by 150 and 98 m^2·day, and in the Forest-steppe by 165 m^2·day. The photosynthetic potential will decrease by 234 m^2·day in the Southern steppe, it will be at the level of the base period in the Northern steppe, and in the Forest-steppe it will be less by 133 m^2·day in the period from 2031 to 2050.

Table 2. Productivity changes of Zagrey under the A2 scenario.

Climatic period	Year	Leaf area (maximum development), m^2/bush	Photosynthetic potential, m^2·day	Total biomass to technical maturity, g/bush	Yield, t/ha
			Southern steppe		
Base	1986-2005	10.6	1011	3060	14.5
I	2011-2030	9.2	861	2679	11.9
II	2031-2050	8.4	777	2378	10.4
			Northern steppe		
Base	1986-2005	10.2	964	2737	13.7
I	2011-2030	9.3	866	2431	12.0
II	2031-2050	10.2	967	2741	13.7
			Forest-steppe		
Base	1986-2005	10.5	994	2845	14.2
I	2011-2030	8.9	829	2320	11.3
II	2031-2050	9.2	861	2438	11.9

The Zagrey yield in 2011-2030 will decrease in the Southern and Northern steppe and the Forest-steppe, respectively, from 14.5 to 11.9, from 13.7 to 12.0 and from 14.2 to 11.3 tons per hectare. The yield will decrease in the Southern steppe and the Forest-steppe in the period from 2031 to 2050 by 4.1 and 2.3 tons per hectare, respectively, and in the Northern steppe the yield will slightly increase by 0.05 tons per hectare. Similarly, modeling and analysis of the obtained results of photosynthetic activity and yield of Rubin tairovskyi under the A1B scenario, as well as in both scenarios, were done.

Conclusion

The modeling of grapevine yield formation of medium and late ripening varieties Zagrey and Rubin tairovskyi indicates the general tendency to shift the beginning of grape development to earlier dates under A1B and A2 climate change scenarios for three climatic periods (1986-2005, 2011-2030 and 2031-2050) in the Southern and Northern steppe, and Forest-steppe. It was observed that in a more severe A2 scenario, agroclimatic resources cause a significant deterioration of photosynthetic activity and, as a consequence, a decrease in grape yields. The study showed that in both climate change scenarios, relatively better conditions are in place for late-ripening varieties in the Southern steppe, and for medium-ripening varieties in the Northern steppe and the Forest-steppe. It is established that under conditions of heat and precipitation supply, it is possible to change the boundary of the viticultural area in the northern regions.

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