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ZÁVISLOST PRODUKTIVITY RÉVY VINNÉ NA METEOROLOGICKÝCH PODMÍNKÁCH V MOLDAVSKÉ REPUBLICE

Dependence of grapevine productivity on meteorological conditions in the Republic of Moldova

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Abstrakt

Korelace mezi produktivitou vinné révy a teplotně-vlhkostních podmínek v Moldavské republice byla hodnocena pro šumivá vína a stolní odrůdy. Posouzení bylo provedeno pro různá časová období (rok, studené a teplé období, jednotlivé měsíce). Prostřednictvím vícenásobné regresní analýzy byly statisticky zjištěny u jednotlivých měsíců jejich kritické meteorologické podmínky pro formování výnosu a akumulaci cukru. Je prokázáno, že teplota vzduchu a srážky mají rozdílný vliv na tyto ukazatele produktivity hroznů. V období rašení a růstu bobulí zvýšení teploty vzduchu nad optimální o 1 °C představuje pokles výnosu o 1,2 q/ ha, rovněž vysoké teploty v době zrání výnosu mají za následek klesající výnosy, avšak podporují zvýšení cukernatosti. Srážky v jakékoli fázi růstu příznivě ovlivňují výnos, ale snižují obsah cukru. Statistické modely umožňují předpovídat v předstihu kvalitativní i kvantitativní parametry sklizně hroznů s dostatečnou úrovní statistické spolehlivosti.

Klíčová slova: vinná réva produktivita, povětrnostní podmínky, ve fázi růstu, statistické vztahy

Abstract

Correlation between grapevine productivity and temperature-humidity conditions in the Republic of Moldova was assessed for sparkling and table wine cultivars. The assessment was carried out for different time-slices (year, cold and warm period, individual months). Through multiple regression analysis there were statistically identified the months critical by their meteorological conditions for yield forming and sugar accumulation. It is shown that air temperature and precipitation differently influence on these indicators of grape productivity. In the period of sprout and berry growth the increase of air temperature over optimum by 1°C results in yield decrease about 1.2 center/ha; in the period of yield ripening the high temperatures, decreasing yields, promote sugar accumulation. Precipitation in any growth phase favorably tells on yield, but reduces sugar content. The developed statistical models allow predicting grape productivity in advance, with the sufficient level of statistical confidence.

Key words: grapevine productivity, meteorological conditions, growth phase, statistical relationships

Introduction

Viticulture is one of the major branches of Moldova's economy, whose products being the first concern of national export. The total vineyards' area covers 166 thousand ha. However, the country is situated at the northern border of world viticulture where grapevine yield and quality are very sensitive to climatic conditions on the whole and to the weather conditions of a year in particular (Ceban 2000). It is also necessary to add that a perennial vine plant remains economically productive during 50-60 years, exposing to inevitable climate variability.

Briefly, a vine phenology may be reduced to several principal phases (Mullins et al. 1992), which in Moldova have the following chronology. Bud break occurs usually in April, over the wide range of variety-specific dates, but its relatively early or late oncoming depends upon weather patterns. The period of intensive vegetative growth, during which the shoots elongate and very rapidly produce leaves, slows down in June when blossom begins. The number of viable fruits (berries) is determined shortly after blossom, and from this moment the maturing berry clusters become the primary sinks for photosynthesis, undergoing two phases of growth: (1) seed development and building of a hard green berry structure; (2) sugar accumulation and rapid enlargement of the berries. The berry maturity of cultivated in Moldova vine varieties is usually reaching during September-October.

This research is aimed to perform a more detailed analysis of monthly air temperature and precipitation influence on grapevine productivity.

Materials and methods

As initial data on grapes productivity, their yields and sugar content (sugariness) were used. 180 varieties, cultivated in the plots of the "Cricova" joint-stock company with different soil and environment, were classified into two data sets depending on their use for the production of either sparkling or table wines (Table 1). Vine productivity was estimated from the 1986-1995 annual yields at each plot. The coefficients of variation *(CV)* of the studied parameters were used as an initial coarse measure of the cultivars' sensitivity to variations in annual weather conditions. If the soils and locations are considered to be fixed in a short-term study, then the weather conditions are the main source of interannual variability of grapevine production. *CVs* show that variability of yields is substantially higher than variability of sugariness, and cultivars for sparkling wines are more sensitive to weather conditions than cultivars for table wines.

Tab. 1: Number *(N)*, area and averaged productivity of the vineyards used in the research

Table wine cultivars	**N**	**Area, ha**	**Yield**		**Sugariness**		**Sparkling wine cultivars**	**N**	**Area, ha**	**Yield**		**Sugariness**	
			c/ha	Cv, %	%	Cv, %				c/ha	Cv, %	%	Cv, %
Feteasca	16	218	75.9	8.1	17.4	4.0	Chardonnay	14	411	66.5	4.79	17.8	4.7
Muscat	4	68	67.8	4.1	17.6	3.8	Pinot	22	635	68.6	5.48	17.9	4.4
Traminer	5	105	68.1	6.2	17.7	4.1	Riesling	6	183	69.2	9.03	17.6	4.7
Rkatsiteli	41	579	72.6	6.8	17.5	4.2	Sauvignon	10	150	76.6	9.97	17.6	4.4
Cabernet	10	145	71.8	6.3	17.4	4.4							
Merlot	8	145	72.3	7.5	17.5	4.3							
Aligote	44	1034	70.8	6.2	17.4	4.0							
Total	**128**	**2294**	**71.3**	**6.3**	**17.5**	**4.0**	**Total**	**52**	**1379**	**70.2**	**7.23**	**17.7**	**4.5**

Surface air temperature and precipitation records at Balțata weather station, located in 15 km from the studied plots, were used to describe meteorological conditions. The following temperature variables were employed: mean monthly temperature; mean minimum monthly temperature of a cold (November-March) period (*CP*); absolute minimum temperature of a cold period; mean maximum monthly temperature of a warm (April-October) period (*WP*);

absolute maximum monthly temperature of a warm period. *WP* monthly precipitation sums as well as *CP* and *WP* sums were used as precipitation variables. All vineyards were not irrigated.

Multiple regression analysis (Statgraphics 2009) was used to assess the dependence of grape productivity on monthly meteorological conditions. The analysis was carried out both for each cultivar and for each grapevine group on average.

Results and discussion

1. 1986-1995 trends in grapevine productivity

1986-1995 yearly grape yields and sugariness for each variety and for both groups were approximated by linear trends (Table 2). During this period, the grape yields were decreasing steadily as it is confirmed by statistically significant negative trends. Correlation coefficients *(r)* of yields with calendar years were above 0.8-0.9 for practically all cultivars. The slightly larger level of decrease is typical for the cultivars of sparkling wines: the trend coefficient equals to -1.53 compared with -1.44 for table wine cultivars. At the same time, there is no statistically significant trend in grape sugar content; in most cases *r* is less than 0.3.

Tab. 2: Parameters of the linear trends $(y = a_0 + a_1\tau)$ of grape productivity, 1986-1995

Direction of use, cultivars	Yield			Sugariness		
	r	a_0	a_1	**r**	a_0	a_1
Sparkling wines	-0.910[c]	3111.61	-1.52794	-0,074	56.431	-0,01945
including:						
Chardonnay	-0.804[b]	1750.84	-0.84618	-0.214	134.895	-0.05884
Pinot	-0.812[b]	2076.71	-1.00885	-0.080	59.967	-0.02115
Riesling	-0.897[c]	3761.44	-1.85491	-0.145	96.464	-0.03963
Sauvignon	-0.952[c]	4861.18	-2.4037	0.164	-65.842	0.04193
Table wines	-0.890[c]	2932.7	-1.43727	0.179	-65.727	0.04181
including:						
Aligote	-0.908[c]	3193.88	-1.56848	0.288	-115.089	0.06654
Cabernet	-0.908[c]	3415.07	-1.67903	0.404	-187.646	0.10303
Muscat	-0.347	701.31	-0.31830	0.004	15.594	0.00103
Merlot	-0.914[c]	3350.00	-1.64667	0.247	-103.96	0.06096
Rcatiteli	-0.917[c]	3642.88	1.79303	0.227	-92.360	0.05521
Traminer	-0.857[b]	2432.54	-1.18788	-0.010	22.792	-0.00254
Feteasca	-0.925[c]	3801.85	-1.87188	0.022	7.1469	0.00515

Note: r – correlation coefficient of productivity with a calendar year; $^a – 0.01 < p \leq 0.05$; $^b – 0.001 < p \leq 0.01$; $^c – p \leq 0.001$ – statistical significance of trend; a_0 – interception; a_1 – coefficient of trend; τ – calendar year.

From a physiological viewpoint, the observed fact can be explained (Corobov et al. 2002) by the bigger dependence of yields on so-called "earthly" ecological factors (soil fertility, farming practices, etc.), while grape sugar content is mainly determined by "cosmic" factors (temperature-precipitation regime and solar radiation). That is why the considerable decrease in the application of organic and mineral fertilizes, plant protection, and agricultural technologies caused by the economic difficulties of the transition period in the Moldova economy, more negatively affected the grape yields than sugariness.

The trend component imposes certain restrictions on the statistical analysis because in this case the real productivity reflects not only a year weather conditions but also the trend change of other impact factors. Proceeding from this, the deviations from trends were considered as a climatically conditioned part of productivity. The *deviations*, reflecting weather-caused origins, were both positive and negative, and *their values were taken as independent variables for the regression analysis.*

2. Dependence of grape productivity on monthly air temperature and precipitation

To solve this problem, the simple correlation dependence of grape yields and sugariness on temperature and precipitation variables, selected for the analysis, was calculated. Correlation coefficients of meteorological variables with the productivity deviations from the trends are shown in Table 3.

Tab. 3: The coefficients of simple correlation *(r)* between the grape productivity deviations from trends and meteorological conditions of a growth period

Month, period of year – Precipitation

Group of use	Productivity parameter	IV	V	VI	VII	VIII	IX	X	CP	WP
SW	Yield	0.782[b]	0.355	0.163	0.518	0.185	0.741[b]	0.017	0.665[a]	0.866[c]
	Sugariness	-0.414	0.065	-0.388	0.266	-0.175	-0.790[b]	-0.406	-0.285	-0.656[a]
TW	Yield	0.768[b]	0.432	0.124	0.576	0.256	0.689[a]	-0.011	0.564	0.886[c]
	Sugariness	-0.333	0.170	-0.373	0.354	-0.220	-0.804[b]	-0.428	-0.280	-0.611[a]

Mean minimal temperatures and cold period absolute minimum

Group of use	Productivity parameter	XI	XII	I	II	III	XI-III	Absolute min
SW	Yield	0.389	-0.450	-0.209	0.252	-0.049	0.046	-0.042
	Sugariness	-0.066	0.616[a]	0.268	-0.651[a]	-0.162	-0.068	-0.126
TW	Yield	0.346	-0.350	-0.195	0.285	-0.052	0.069	-0.075
	Sugariness	0.009	0.609	0.286	-0.657[a]	-0.137	-0.025	-0.060

Cold period mean temperatures

Group of use	Productivity parameter	XI	XII	I	II	III	XI-III
SW	Yield	0.400	-0.241	-0.267	0.247	-0.192	-0.022
	Sugariness	-0.058	0.597	0.333	-0.625[a]	-0.093	-0.022
TW	Yield	0.370	-0.190	-0.232	0.277	-0.157	0.044
	Sugariness	0.020	0.571	0.351	-0.626[a]	-0.082	0.008

Absolute maximal temperatures of warm period

Group of use	Productivity parameter	IV	V	VI	VII	VIII	IX	X
SW	Yield	-0.327	-0.002	-0.257	0.396	0.012	-0.492	-0.058
	Sugariness	0.170	-0.200	0.142	-0.384	-0.194	0.030	0.197
TW	Yield	-0.326	-0.004	-0.202	0.386	-0.100	-0.505	0.008
	Sugariness	0.115	-0.300	0.110	-0.399	-0.204	-0.022	0.243

Mean maximal temperatures of warm period

Group of use	Productivity parameter	IV	V	VI	VII	VIII	IX	X
SW	Yield	0.091	-0.386	-0.043	0.500	-0.377	-0.050	-0.072
	Sugariness	0.059	0.313	0.302	-0.315	-0.039	0.476	0.123
TW	Yield	0.109	-0.420	0.018	0.471	-0.492	-0.047	0.005
	Sugariness	0.082	0.272	0.248	-0.275	-0.044	0.502	0.180

Mean temperatures of warm period

Group of use	Productivity parameter	IV	V	VI	VII	VIII	IX	X	$\Sigma T>10^{o}C$
SW	Yield	-0.444	-0.363	0.004	0.234	-0.473	-0.625[a]	-0.114	-0.160
	Sugariness	0.347	0.408	0.228	0.067	0.062	0.638[a]	-0.264	0.284
TW	Yield	-0.386	-0.385	0.052	0.285	-0.587	-0.601	-0.154	-0.079
	Sugariness	0.312	0.355	0.164	0.125	0.042	0.567	-0.276	0.254

Note: SW – the vine cultivars used for sparkling wines; TW – the vine cultivars used for table wines; CP – cold period; WP – warm period

Air temperature influence. Dependence of *grape yields* on the averaged temperature conditions of a cold period is practically absent (*r* with November-February average temperature is close to zero for the both groups of cultivars). Correlation is weak and statistically insignificant for individual months too. However, some regularity is beyond doubt, what is seen especially well in Fig. 1. Here, for the better analysis and clearness of results, main information of Table 3 is additionally depicted as diagrams. The revealed regularity can be reduced to the following statements:

1. The next year yield are promoted by higher November temperatures and, perhaps, by higher *positive* February temperatures. In December and January there is a negative correlation. Taking into account that in these months the mean temperatures in Moldova are, as a rule, negative, such a form of dependence means that more low temperature in this period are more favorable for a future yield. However, in March when mean temperatures are positive the negative correlation results in an adverse affect.
2. As a result of the different directions in temperature influences of the individual months, the cold period averages have practically no useful information about a future yield.
3. The different varieties dependence on cold period temperature conditions is practically identical by its tendency.

a)

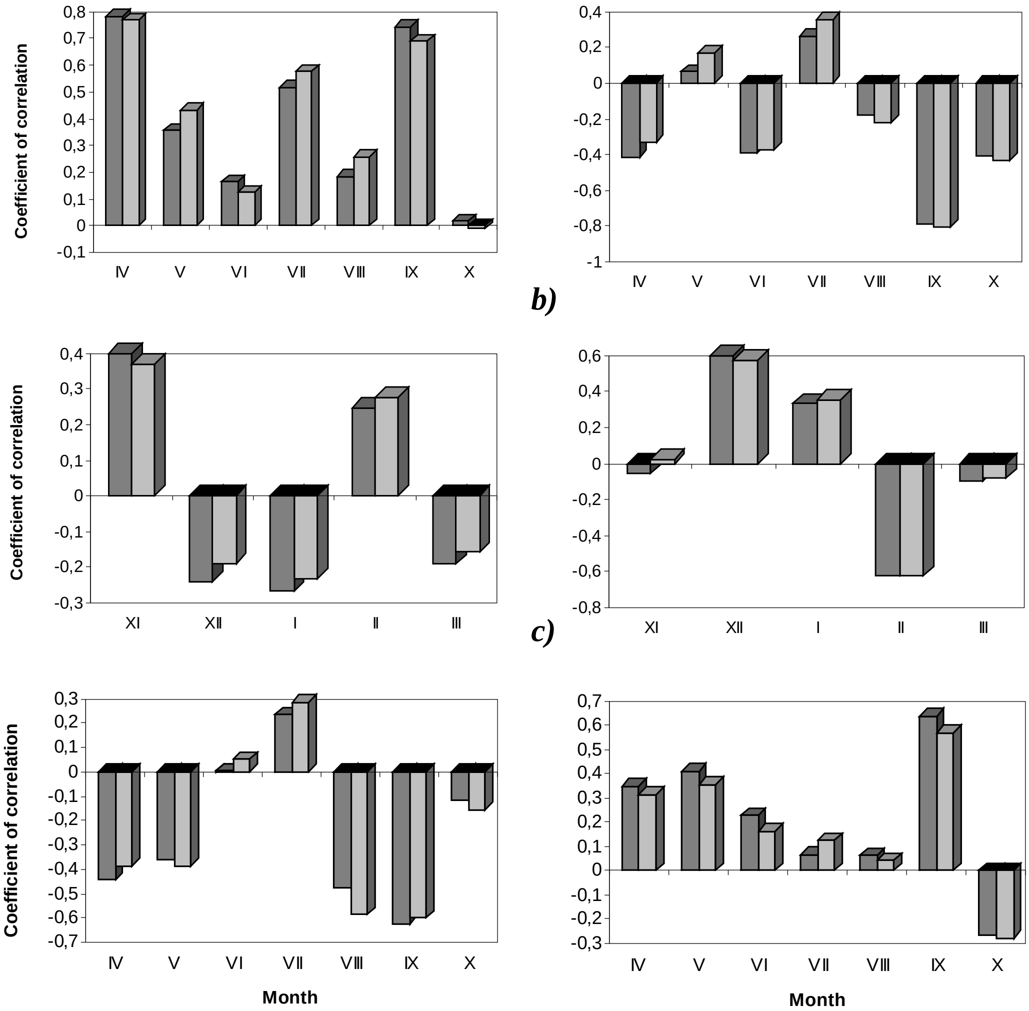

Fig. 1: Diagrams of simple correlation of meteorological conditions with the deviations from trends of grape yields (left) and sugar content (right).

– cultivars used for sparkling wines;
– cultivars used for table wines;
a) – with cold period precipitation;
b) – with cold period mean monthly temperature;
c) – with warm period mean monthly temperature.

On the whole, the heat supply of Moldova territory is sufficient for vine ripening, and higher temperatures in *a warm period*, especially in August and September, usually affect a grape yield negatively; a positive temperature effect takes place in June-July only. This conclusion results from the fact that during a hot weather the plants spend more energy for breathing and transpiration (warm balance regulation) in order to provide for biological protection of forming the generative potential of full value. However, this process leads to the detriment of an economically useful yield, negatively affecting the storage of vegetative mass and a grape size. Our results well agree with modeled results for Italy (Bindi et al. 1995) where the negative effect of above-optimum temperatures on berry and total dry matter is also explained by shortening of a growing season and a berry-filling period.

As it was expected, the effect of temperature on sugar content in grapes is opposite. The lower temperatures in the *CP's* months, especially in December and January, negatively influence sugar accumulation, but colder February promotes this process. Positive influence of February low temperatures on sugar content we can explain by the possible damage of more fruitful central buds that can prematurely "wake up" in warm February. Dependence of sugariness on the temperature conditions is higher than that for a yield. This fact once more confirms the conclusion that sugar content in grapes is more dependent on dynamically changing ecological factors as which climatic ones are.

Precipitation influence on grapevine productivity as compared to air temperature is expressed more clearly both for warm and cold periods: *in any growth phase, precipitation favorably affects yields but, as a rule, reduces sugariness.*

So, the correlation coefficient of *yields* with cold period precipitation totals amounts to 0.56 for grapes cultivated for table wines and 0.66 – for sparkling ones, i.e. precipitation in this period determines from about one third to half of annual yield variability. The weight of warm period precipitation is yet more – about 75% of the yield's variance *(r = 0.87-0.89).* Precipitation influence is the most in April (phase of sap movement), in July (phase of berry growth) and especially in September, in the period of ripening.

Sugar content is promoted in some degree by May and July precipitation only; in rest months the correlation is negative. Above all the sugar content is determined by September precipitation (about 50% of annual variability); 10-15% of variability is determined by a cold period precipitation.

3. Statistical models for a grape productivity prognosis

The above-described dependencies of grapevine yield and sugariness on monthly meteorological conditions are of interest mainly from the viewpoint of studying these parameters productivity' genesis. However, the prognostic value of such information comes practically to nought because of multiplicity and sometimes (depending on a period of growth) of the different directions of temperature and precipitation influences on final vine productivity; a thorough prognosis can be received only through complex considering both variables' joint impacts considered together in a model. The tasks of such kind are best addressed by multiple regression techniques that develop statistical relationships between one dependent variable (predictant) and a suite of independent variables (predictors). The corresponding procedures result in some final multiple regression equations where only those variables remain whose influence on the dependent variable is significant (Statgraphics 2009, Ulanova and Zabelin 1990).

Tab. 4: Statistical models of grape yield prognosis at different phases of growth

Groups	Phenology phase	R^2, %	R	p	Error		Coefficients of regression								
					St.	Abs.	a_0	a_{Pcp}	a_{T02}	a_{P04}	a_{T07}	a_{P07}	a_{T08}	a_{T09}	a_{P09}
For sparkling wines	Winter dormancy	60.1	0.698	0.040	1.51	1.06	-4.25	0.038	0.256	-	-	-	-	-	-
	Sap movement	73.1	0.773	0.038	1.33	0.91	-4.26	0.022	0.174	0.061	-	-	-	-	-
	Blossom - berry growth	98.0	0.977	0.002	0.45	0.20	20.47	0.019	0.348	0.077	-1.295	0.039	-	-	-
	Berry ripening	99.0	0.985	0.004	0.36	0.16	17.97	-	-	0.057	-0.754	0.028	-0.225	-0.120	0.023
For table wines	Winter dormancy	48.3	0.580	0.099	1.81	1.27	-3.88	0.035	0.277	-	-	-	-	-	-
	Sap movement	66.2	0.702	0.073	1.58	1.08	-3.89	0.015	0.175	0.075	-	-	-	-	-
	Blossom - berry growth	94.2	0.932	0.014	0.81	0.37	18.98	0.015	0.438	0.062	-1.217	0.059	-	-	-
	Berry ripening	99.0	0.985	0.004	0.39	0.17	19.33	-	-	0.019	-0.466	0.037	-0.434	-0.268	0.026

Tab. 6: Statistical models of grape sugariness prognosis at different phases of growth

Groups	Phenology phase	R^2, %	*R*	p	Error		Coefficients of regression							
					St.	Abs.	a_0	a_{Pcp}	a_{T12}	a_{T02}	a_{P04}	a_{P06}	$a_{T\ amax\ 07}$	a_{P09}
For sparkling wines	Winter dormancy	87.4	0.900	0.004	0.34	0.20	0.68	-0.005	0.206	-0.171	-	-	-	-
	Sap movement	87.5	0.881	0.017	0.37	0.19	0.68	-0.004	0.205	-0.168	-0.002	-	-	-
	Blossom - berry growth	97.1	0.973	0.005	0.18	0.11	10.88	-	0.176	-0.111	-	-0.009	-0.299	-
	Berry ripening	99.0	0.988	0.0004	0.12	0.06	8.45	-	0.171	-0.089	-	-0.007	-0.227	-0.004
For table wines	Winter dormancy	84.5	0.876	0.008	0.34	0.20	0.59	-0.005	0.173	-0.151	-	-	-	-
	Sap movement	78.9	0.826	0.018	0.39	0.27	0.23	-	0.188	-0.136	-0.005	-	-	-
	Blossom - berry growth	95.2	0.956	0.002	0.20	0.12	9.91	-	0.145	-0.097	-	-0.008	-0.273	-
	Berry ripening	97.8	0.975	0.002	0.15	0.07	7.45	-	0.141	-0.074	-	-0.006	-0.199	-0.004

Conventional signs:

1. R^2 – coefficient of determination; R – coefficient of multiple regression;
2. Lower indexes: T_i – *i*-month mean temperature; T_{amax} – absolute maximum temperature; P_i – *i*-month precipitation; P_{cp} – cold period precipitations total.
3. *p* – statistical significance of a model; *St.*, *Abs.* – standard and absolute errors respectively.

In Tables 4 and 5 there are cited the statistical models of grape yield and sugariness dependence on the temperature-precipitation conditions of a preceding period. The variables, residuary in the models, have been selected by two ways:

1) the stepwise regression analysis with consecutive entering of each variable into the model or, on the contrary, its consecutive removing from the model;
2) selection of the “best” subset (most informative combination) of regression model explanatory variables.

In these tables the coefficient of determination R^2 shows a proportion of year-to-year variability in productivity that is explained by the subset of selected variables. *P*-value *(p)* estimates statistical significance of a model. In our case, this parameter is everywhere over 95% confidence level $(p < 0.05)$ accepted in biology; in most cases it is over 99% level $(p < 0.01)$.

Let us to analyze the equations for the individual periods of vine vegetation, simultaneously considering them as *statistical models for productivity prognosis* at these phases of plant development. Herewith, it should be noted that all following estimations are expressed as the expected deviations from the long-term trends.

Winter dormancy. The temperature-humidity conditions of a preceding cold period determine almost half of future yields of sparkling cultivars and almost a third of table wine cultivars yields. There are confirmed the above-mentioned prevalent positive influence of precipitation in this period as well as the influence of February temperatures. The influence of meteorological conditions in the rest months, being considered in common, is not confirmed statistically.

As to the prognosis of sugariness, one should take into account a small negative influence of precipitation (sugar content changes by about 0,05% per every 10 mm of precipitation) as well as December and February mean temperatures, whose influence is approximately equal by power (0.2% per degree of temperature change), but opposite by a sign.

Sap movement. The meteorological conditions in this phase of vine development significantly affect neither final grape yield nor their sugariness. Therefore, the prognosis based on winter conditions can be used. To confirm this statement, in the second raw of Table 6 there is shown a model into which April precipitations are included. R^2 – the explained part of sugariness variance – increased by 0.1% only.

Blossom–berry growth. Information value of a prognosis made in this period of vine development amounts to 95-97%, with high statistical significance $(p < 0.01)$. July meteorological conditions are critical for yield. Every 1°C above a mean monthly temperature lessens a yield by 1.2-1.3 center/ha; at the same time, July precipitations favor to yield. Including these parameters into the statistical model of grape yield raises its informativity to 98% for sparkling cultivars and to 94.2% – for table ones. A more complex picture is for grapes sugariness. Precipitation totals during a blossom (June) as well as July hot temperatures reduce the sugar content in berries.

Berry maturing. The meteorological conditions of this period practically completely form a future yield prognosis, raising R^2 nearly to 1. It is confirmed the extreme importance of September weather for vine productivity: this month precipitation is favorable for yields, while August-September air temperatures are unfavorable. Such influence is manifested approximately twice stronger in cultivars for table wines.

Conclusion

Weather impacts on grapevine yield and quality are highly dependent on the stage of a vine plant development. During winter dormancy the most crucial for productivity are meteorological conditions of the following months:

- *for yields* – February;
- *for sugar content* – December and February.

The influence of meteorological conditions during grapevine vegetation can be divided on two stages: the first – period of sprout and berry growth; the second – period of yield ripening. In the first period the 1°C increase of air temperature over its optimum results in yield decrease by 1.2 centers per ha and more; precipitation, on the contrary, favors to yields. In the second period a temperature-precipitation regime more affects sugar accumulation. The most crucial month is September, and to make the final prognosis of sugariness it is enough to take into account this month precipitation. Additional consideration of mean temperatures, closely correlating with precipitation, does not give new information.

Thus, the complex research of grapevine productivity dependence on the meteorological conditions of plant growing gives an opportunity to address the several important tasks:

- to quantify the degree of grapevine yield and sugariness dependence on annual meteorological conditions;
- to give well in advance, with different time-slices, the statistical prognosis of expected yield and to estimate statistical reliability of the prognosis;
- to evaluate in advance the climatic component of the general potential of a territory planned for cultivating grapevine as a culture on the whole, as well as of the set of cultivars with different directions of using.

And, at last, in the conditions of global warming, the research findings give an opportunity for the qualitative and quantitative investigations of likely climate change impacts on Moldova grapevine production (Corobov 2007).

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