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GIS-AIDED ANALYSIS OF VINEYARDS DAMAGED BY WINTER FROSTS. CASE STUDY: COTNARI VINEYARD (ROMANIA)

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ABSTRACT. Thermal regime of Cotnari vineyard, Iaşi County, Romania, was surveyed between 2011-2012 using 10 Tinytag temperature loggers TK-4014, spread in 10 different lands of the vineyard. Research is developed in the framework of the international project TERVICLIM (France), by means of was created a global network of analyses points of vineyard climate, spread in 13 countries from both hemispheres of the globe, at different latitudes. The data recorded by temperature loggers in Cotnari vineyard shows that in 2011-2012 winter, the minimum temperatures dropped to -28.6ºC, with differences of up to 7.1ºC between the coldest and the mildest lands of the vineyard. Spatial distribution of the most harmful frost (12 February 2012) shows that more than 80% from the vineyard area was exposed to temperatures lower than -24ºC, 17% to harmful temperatures between -21..-24ºC and 3% to temperatures between -18..-21ºC, less damaging to vines. As consequences, the damages in the vine plantations varied from less significant negative consequences for vines in the mildest location, up to massive losses of winter buds, damages of annual branches and frozen vines in the coldest land of the vineyard. Analytical data of winter buds losses spatial distribution shows that at -28.6ºC (absolute minimum temperature for the vineyard), 0.46% (7.29 ha) of vine plantations were exposed to vines losses, 3.81% of plantations to losses of annual branches, 62.49% from vine plantations to winter buds losses exceeding 40%, difficult to compensate by pruning, 13.5% to losses of winter buds exceeding 60%, requiring reestablishing the vegetative potential of vines. The only vine plantations protected by harmful frosts were those located at over 175 m altitude, in the highest lands of the vineyards.

Key words: Vines; Vineyard; Frost; Winter buds; Temperature loggers; GIS.

REZUMAT. Analiza asistată de Sistemul Informatic Geografic (SIG) a podgoriilor afectate de înghețuri. Studiu de caz:

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podgoria Cotnari, România. Regimul termic al podgoriei Cotnari a fost monitorizat în perioada 2011-2012 cu ajutorul a 10 senzori termici Tinytag TK-4014, amplasați în 10 locații diferite din podgorie. Cercetarea se desfășoară în cadrul proiectului internațional TERVICLIM (Univ. Rennes 2, Franța), prin care s-a creat o rețea de monitorizare a climatului arealelor viticole cu puncte de observație în 20 de podgorii din 13 țări, situate la diferite latitudini, în ambele emisfere ale globului. Datele înregistrate de senzorii termici Tinytag în podgoria Cotnari arată că, în iarna 2011-2012, temperaturile minime negative au coborât până la -28.6ºC (12 februarie 2012), cu diferențe de până la 7.1ºC între cel mai rece şi cel mai puțin rece plai al podgoriei. Din analiza distribuției spațiale a gerului din data de 12 februarie 2012 rezultă că mai mult de 80% din plantațiile viticole ale podgoriei au fost expuse la temperaturi mai mici de -24ºC (dăunătoare pentru lemnul multianual), 17% la temperaturi de -21…-24ºC (dăunătoare pentru ochii de iarnă şi lemnul anual) şi 3% la temperaturi de -18..-21ºC (mai puțin dăunătoare pentru vița de vie). Ca urmare, daunele produse plantațiilor viticole au variat de la nesemnificative pe plaiurile cu climat blând, până la pierderi masive de ochi de iarnă, distrugerea prin îngheț a coardelor anuale şi chiar distrugerea prin îngheț a butucilor de viță de vie. Datele analitice privind distribuția spațială a daunelor provocate viței de vie arată că, la temperatura de -28.6ºC (minima absolută din iarna 2011-2012), 0.46% (7.29 ha) din suprafața podgoriei a fost expusă distrugerii butucilor de viță de vie, 3.81% distrugerii coardelor anuale, 62.49% pierderilor de muguri mai mari de 40%, dificil de compensat prin tăieri, 13.5% pierderilor de muguri care depășesc 60% şi care impun refacerea butucilor de viță de vie. Singurele plantații ferite de înghețurile nocive din iarna 2011-2012 au fost cele situate la mai mult de 175 m altitudine.

Cuvinte cheie: butuci de viță de vie; podgorie; îngheț; ochi de iarnă; senzori termici; SIG.

INTRODUCTION

Begging with the year 2011 Cotnari vineyard is part of a network of 20 monitoring points of vineyard climate, spread over the world, from Europe (France, Germany, Portugal, Spain) to South America (Chile, Argentina, Bolivia), Africa (South Africa), Australia, New Zealand and even Indian Ocean (Reunion Islands). The research, developed within the international project TERVICLIM (Univ. Rennes 2, France), aim to analyze at micro-scale the vineyard climate changes determined by global warming, by using thermal sensors (Tinytag TK-4014 temperature loggers) placed in vineyards at different latitudes in both hemispheres of the globe (Quénol *et al.,* 2009, 2012; Quenol, 2011; Bonnefoy *et al.,* 2010; Barbeau *et al.,* 2011; Patriche *et al.,* 2011; Irimia *et al.,* 2012).

With its 47º northern latitude location, Cotnari vineyard is the northernmost of the vineyards analyzed in this study. So here are producing every 3-4 years severe frosts affecting vines that require practicing different measures to protect vines during the winter, as are: covering basal branches with soil; training cordons at different levels; high trunk training systems. Placing sensors Cotnari vineyard permitted us to analyze the frost produced in 2011-2012 winter, when the minimum temperatures dropped down up to –

28.6ºC, close to the record for the vineyard (–29.0ºC). GIS analysis of the results, made in the context of a longer-lasting research taking place in the vineyards of Moldova region (Patriche *et al.,* 2009; Irimia and Patriche, 2009, 2010; Irimia *et al.,* 2011, 2012), furtherance the results and allowed us to establish the spatial distribution of frosts and of damages produced to vines.

MATERIALS AND METHODS

Cotnari vineyard is located in the eastern part of Romania, in the Moldavian Plateau, at 47º20'52" N, 26º56'37" E. The vineyard relief is hilly, with an important altitude and slope exposure variation in an area of 1569 ha vine plantations. The vine plantations are located especially on slopes with S, SE and SV aspects, the N exposure being unfavorable for vine culture. The negative temperatures, damaging for vines (-20…-22ºC), occur in the vineyard with a 3-4 years frequency, determining loss of winter buds by 20-40%, that are compensated by secondary buds growing, that assure normal yields. Rarely, the negative temperatures drop down to -29ºC, the record for this vineyard, determining important losses of winter buds, annual branches and even vines in some exposed areas. For protecting vines during the winter, in the vineyard is practiced the protected cultivation system of vines, characterized by covering with soil in the autumn the base of the trunk and few annual branches. The vineyard assortment is constituted by four autochthonous vine varieties, well adapted to local climate conditions, respectively Fetească albă, Frâncuşă, Grasă de Cotnari and Tămâioasa românească, characterized by a middle resistance to frost (-20…-22ºC) and a short vegetation period, that assure a early maturation of grapes.

For the study of climate thermal variations, in ten of the most representative lands of Cotnari vineyard were placed ten Tinytag TK-4014 temperature loggers *(Fig. 1)*. The locations are spread over the entire surface of Cotnari vineyard, from 125 m altitude in Juleşti 1, the lowermost land of vineyard, up to 300 m in Naslău, one of the highest lands of the vineyard *(Fig. 2)*. The delineation of Cotnari vineyard was based on satellite images integrated in Google Earth.

Figure 1 - Tinytag TK- 4014 temperature loggers in Cotnari vineyard

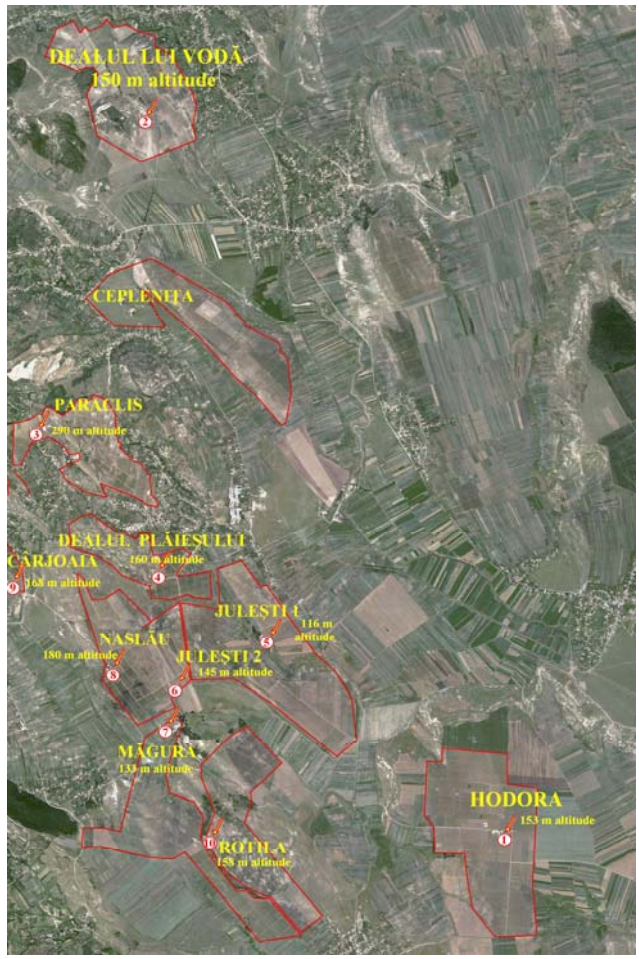

Figure 2 - TK-4014 Tinytag temperature loggers placement in Cotnari vineyard

To establish the winter buds, annual branches and vines losses produced by the frosts during the 2011-2012 winter, two field investigations were conducted: the first, aiming to establish the loss of buds and the viability of annual branches tissues of vines, held at the end of the winter (20-26.02. 2012) after passing frosts; the second one, aiming to establish the percentage of frozen vines, held in the spring (12-17.05.2012). The analyses were made for each of the four varieties, in the plots near the thermal sensors.

The losses of buds were established by cutting buds and examining the internal tissues; the annual branches viability was analyzed by examining the xylem and phloem tissues. The determinations were effectuated on 32 samples from the eight locations were the sensors were placed. For every location were obtained 4 samples, corresponding to the four varieties, each of them being made by 15 buds branches from 1% of the plot vines.

RESULTS AND DISCUSSION

The analyzes of frosts spatial distribution

The damaging frosts occurred between 8 and 12 February 2012, when the minimum temperatures were below the freezing resistance of the vines for 5 consecutive days (*Table 1*). The absolute minimum temperature was -28.6ºC (12 February 2012) in Juleşti 1 land, the lowest location in the vineyard. In the same day, at Paraclis land, located at less than 1 km distance, the minimum temperature was by -21.5ºC, less harmful for vines. There is a significant difference by 7.1ºC between the two lands, that shows that climatic conditions in the vineyard are variable, as well as the suitability for grapevine culture.

The spatial distribution of 12 February frost show that more than 80% from the vineyard area was exposed to temperatures lower than -24ºC, over the limit of vine multiannual branches resistance to frost (*Table 2*). Quite 17% from the vine plantations were exposed to temperatures between -21..-24º, that affected severely the winter buds viability. The frost spatial distribution map shows that were exposed to damaging frosts all the vines located under 185-175m altitude (*Fig. 3*). The only protected vineyard areas were those located at higher altitude, in Paraclis land, totalizing 43.74 ha, less than 3% from the entire vineyard area.

Table 1 - The main characteristics of the frosts period during February 2012, in Cotnari vineyard

Month/ Day/ Year	Land (location of Tinytag data loggers)							
	Hodora	Dealul lui Vodă	Paraclis	Plăieşu	Juleşti 1	Juleşti 2	Măgura	Naslău
2/8/2012	-24.2	-24.6	-19.9	-22.8	-26.7	-23.3	-26.9	-20.5
2/9/2012	-21.7	-22.2	-18.2	-22.1	24.5	-21.2	-27.4	-20.0
2/10/2012	-19.5	-19.6	-17.2	-20.1	-22.6	-18.5	-23.9	-16.9
2/11/2012	-23.0	-24.1	-20.0	-22.6	-26.8	-24.8	-27.6	-20.9
2/12/2012	-24.3	-26.3	-21.5	-24.7	-28.6	-25.1	-28.0	-22.7
Minimum temperature in February (ºC)	-24.3	- 26.3	- 21.5	- 24.7	- 28.6	- 25.1	- 28.0	- 23.4

Table 2 - 12 February 2012 frost spatial distribution in Cotnari vineyard

Temperatures classes (ºC)	Surface (ha)	%
< -24	1256.31	80.03
-24...-21	269.73	17.18
-21...-18	43.74	2.78
> -18	0.00	0.00
Total	**1569.78**	**100**

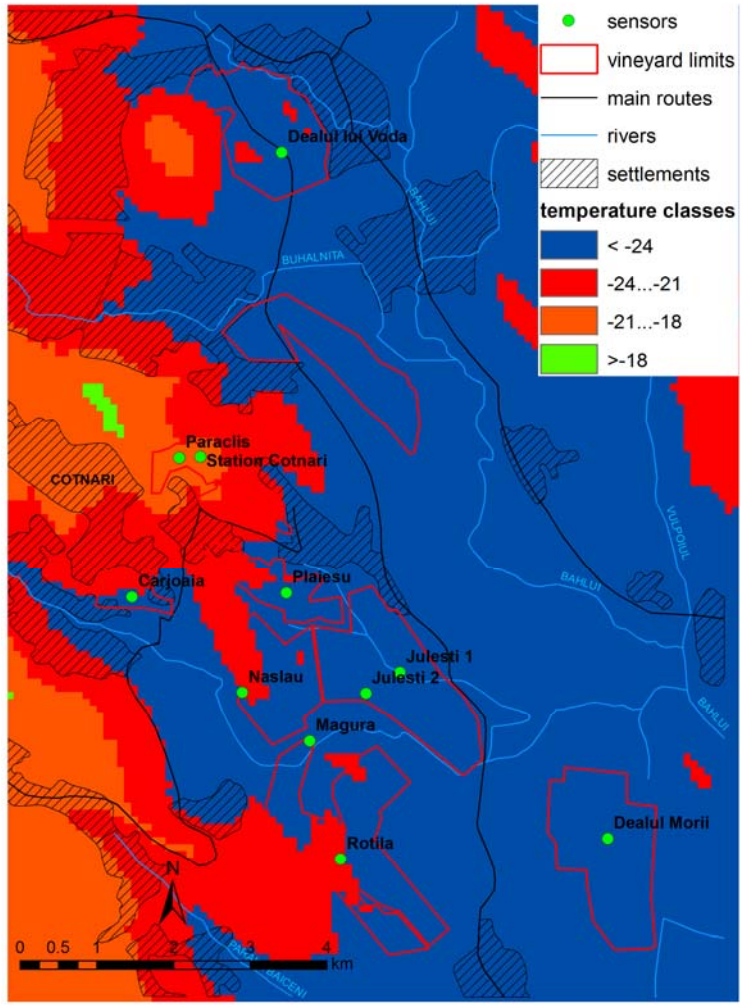

Figure 3 - The 12 February 2012 frost spatial distribution in Cotnari vineyard

The analyze of winter buds losses regarding the grapevine varieties

The results shows that the negative temperatures registered in Cotnari vineyard in 2011-2012 winter had a different negative impact on the vines, in relation to the agro biological characteristics of the four varieties and their location in the vineyard area. The absolute average of buds looses were 47.33%, but with significant differences both between varieties and different sites analyzed (*Table 3*).

Table 3 – The damages caused by winter frosts in the winter 2011-2012 in Cotnari vineyard, in the vine plantations from lands surveyed with Tinytag temperature loggers TK-4014

Damages in vine plantations (%)		Land (location of Tinytag TK-4014 temperature loggers)																									Average		
		Hodora			Dealul lui Vodă			Paraclis			Plăieşu			Juleşti 1			Juleşti 2			Măgura			Naslău					
		Winter buds	Annual branches	Vines	Winter buds	Annual branches	Vines	Winter buds	Annual branches	Vines	Winter buds	Annual branches	Vines	Winter buds	Annual branches	Vines	Winter buds	Annual branches	Vines	Winter buds	Annual branches	Vines	Winter buds	Annual branches	Vines	Winter buds	Annual branches	Vines
VARIETIES	Fetească albă	22.7	-	-	49.2	-	-	17.3	-	-	25.4	-	-	67.1	-	-	32.6	-	-	64.2	-	-	19.8	-	-	37.2	-	-
	Grasă de Cotnari	24.6	-	-	54.6	-	-	18.8	-	-	23.8	-	-	74.6	32.4	-	30.4	-	-	72.8	28.2	-	18.2	-	-	39.7	-	-
	Frâncuşă	33.2	-	-	69.8	-	-	23.4	-	-	30.7	-	-	89.6	63.3	-	53.2	-	-	86.1	58.4	-	28.6	-	-	51.8	-	-
	Tămâioasă românească	46.1	-	-	82.3	53.0		28.2	-	-	41.4	-	-	91.6	88.1	11	46.3	-	-	93.4	70.2	17	32.2	-	-	60.5	-	-
Average (%)		**31.65**		**-**	**63.9**			**21.9**		**-**	**30.3**		**-**	**80.7**		**-**	**46.25**	**-**	**-**	**79.1**	**-**	**-**	**24.7**	**-**	**-**	**47.3**	**-**	**-**

Regarding the varieties, the lowest losses were recorded at Fetească albă variety (absolute average 37.29%), and the biggest at Tămâioasă românească variety (60.50% bud losses). For each variety the losses significantly varied from the levels characteristic to mild winters that do not affect the yields level, to the entire destruction of vines. Such as:

- at Fetească albă variety, the most resistant to frost, the bud losses from the 8 locations analyzed were between 17.3% at Paraclis land and 67.1% at Juleşti 1 land *(Table 3);* at this variety the frost destroyed only winter buds, not annual and multiannual branches of vines;
- at Grasă de Cotnari variety, bud losses were between 18.2% at Naslău and 74.6% at Juleşti 1 land; in plots of Juleşti and Măgura lands were destroyed by low temperatures the annual branches at 32.4% and respectively 28.2% of vines;
- at Frâncuşă variey, the bud losses were between 23.4% at Paraclis land and 89.6% at Juleşti land; 63.3% of vines had the annual branches destroyed in Juleşti 1 plot and 58.4% in Măgura plot *(Table 3).*
- Tămâioasă românească variety registered the biggest losses, the bud destroyed varying between 28.2% in Paraclis plot and 93.4% in Măgura plot; in Juleşti 2, Dealul lui Vodă, Măgura and Juleşti 1 plots, at 46-88% of the vines were destroyed the annual branches; in Juleşti 1 and Măgura plots, determinations during the vegetation period revealed destruction by freezing of the entire aerial part at 11%, respectively 17% of vines *(Table 3).*

The analyze of winter buds losses according to the plots locations

The results shows that the lowest winter buds losses were in Paraclis land (21.93% absolute average) and Naslău land (absolute average of 24.7%), and the highest in Juleşti 1 land (80.73%) and Măgura land (79.13%) *(Table 3).* The winter buds losses in the 8 lands analyzed shows at it follows:

- at Paraclis and Naslău, the winter buds losses at the more resistant to frost varieties Grasă de Cotnari and Fetească albă were small (17.3-18.8%, respectively 18.2-19.8%), while at Frâncuşă and Tămâioasă românească were medium (23.40%-28.20%), but the recorded values doesn't affected vegetative and productive potential of vines;
- in Hodora, Plăieşu and Juleşti 2 lands, the buds losses at the more resistant to frost varieties Grasă de Cotnari and Fetească albă were medium (24.6-30.4%, respectively 22.7-32.6%); in the case of most sensible varieties Frâncuşă and Tămâioasă românească the losses were bigger (53.2% and respectively 68.8%);
- at Dealul lui Vodă land the losses were higher in all four varieties, particularly at Frâncuşă (69.8%) and Tămâioasă românească (82%) varieties; at Tămâioasa românească variety, the most sensible to frost, the

annual branches were destroyed at 46% of the vines;
- at Măgura and Juleşti 1 lands, the locations with the biggest damages produced to the vines, occurred following losses: the winter buds destroyed level was 64.2 - 93.4%, with minimum values at the most resistant to frost varieties Fetească albă (64.2-67.1%) and Grasă de Cotnari (72.8-74.6%), and the biggest to Frâncuşă (86.1-89.6%) and Tămâioasă românească (91.6-93.4%); the annual branches were destroyed at 22-24% of vines at Fetească albă, 28-32% at Grasă de Cotnari, 58-63% at Frâncuşă and 48-88% at Tămâioasă românească variety; 11% of the vines were destroyed in Juleşti land and 17% in Măgura land.

Statistical analyzes of bud losses according to land and climate characteristics

The big number of observation points, the geomorphologic diversity of the area and the variability of losses caused to vines by the frosts from 2011-2012 winter imposed some additional analysis. For this were calculated: (I) the determination coefficient (R^2) between the bud losses and land altitude; (II) the determination coefficient (R^2) between bud losses and minimum negative temperatures between 28.01.2012 – 23.02.2012, when were registered the lowest temperatures. The data are presented in *Table 4.*

The results revealed following aspects:

- the determination coefficient between the altitude and the bud losses is distinct significant (R^2 = 0,7715; F = 20,258; p = 0,004). This explain the high level of bud losses registered in the lowest lands of the vineyard, Măgura and Juleşti 1, respectivelly *(Fig. 4);*
- the determination coefficient between the sum of minimum temperatures and winter buds losses is very significant (R^2 = 0.694, F = 13.6, p = 0.01); the negative temperatures acted also by their duration, that explain the bud losses in the lands where the minimum temperatures were not very low, as Paraclis land is *(Fig. 5);*

GIS representation of winter buds losses spatial distribution in Cotnari vineyard

The distinctive values of determination coefficient between the altitude and the bud losses were used as arguments to calculate the spatial distribution of winter bud losses in the analyzed area *(Fig. 6).* The results shows, on the one hand the unequal distribution of winter bud losses caused by the frost, and on the other hand, the location of plantations in the highest areas of the vineyard, protected by damaging frosts. The biggest bud losses are correlated with the most exposed terrains to frost in the vineyard, an argument to exclude the unfavorable areas from new plantings and for zoning the varieties in the vineyard according to their resistance to frost.

Table 4 - Additional parameters used to characterize the harmful effect of the frosts between 8-12 February 2012 on the vines, in Cotnari vineyard

Parameters	Land (location of Tinytag TK-4014 temperature loggers)								Average
	Hodora	Dealul lui Vodă	Paraclis	Plăieşu	Juleşti 1	Juleşti 2	Măgura	Naslău	
Altitude (m)	164.2	139.2	275.2	163.0	114.9	142.3	129. 2	179.8	-
Average temperature for February (°C)	-15.6	-16.8	-13.9	-15.6	-18.4	-15.9	-18	-14.8	-
Sum of minimum temperature between 8-12 February 2012	-421.6	-453.7	-375.7	-422.5	-497.1	-429.3	-430.5	-348.5	-
The minimum temperature (°C)	-24.3	-26.3	-21.5	-24.7	-28.6	-25.1	-28	-23.4	-
Winter bud losses (%)	**31.65**	**63.98**	**21.93**	**30.33**	**80.73**	**46.25**	**79.13**	**24.70**	**47.3%**

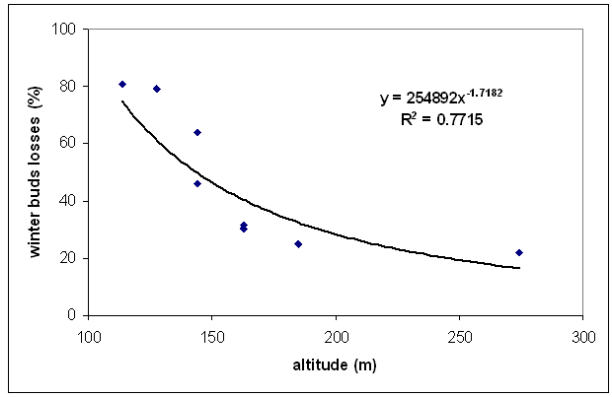

Figure 4 - The determination coefficient between the altitude and the winter buds losses

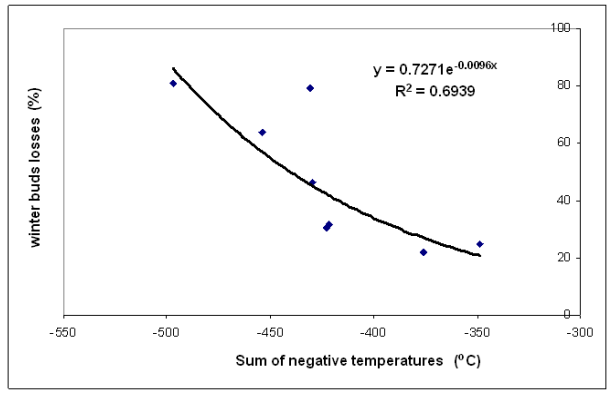

Figure 5 - The determination coefficient between the sum of negative temperatures and winter bud losses

Table 5 - Analitical data regarding the spatial distribution of winter bud losses in vine plantations of Cotnari vineyard in the winter of 2011-2012

The winter buds losses (%)	Surface in the vineyard plantations (ha)	% in total vineyard plantations
< 20	59.94	3.82
20-30	174.15	11.09
30-40	354.78	22.60
40-50	433.35	27.61
50-60	342.63	21.83
60-70	144.99	9.24
70-80	52.65	3.35
> 80	7.29	0.46
Total	**1569.78**	**100**

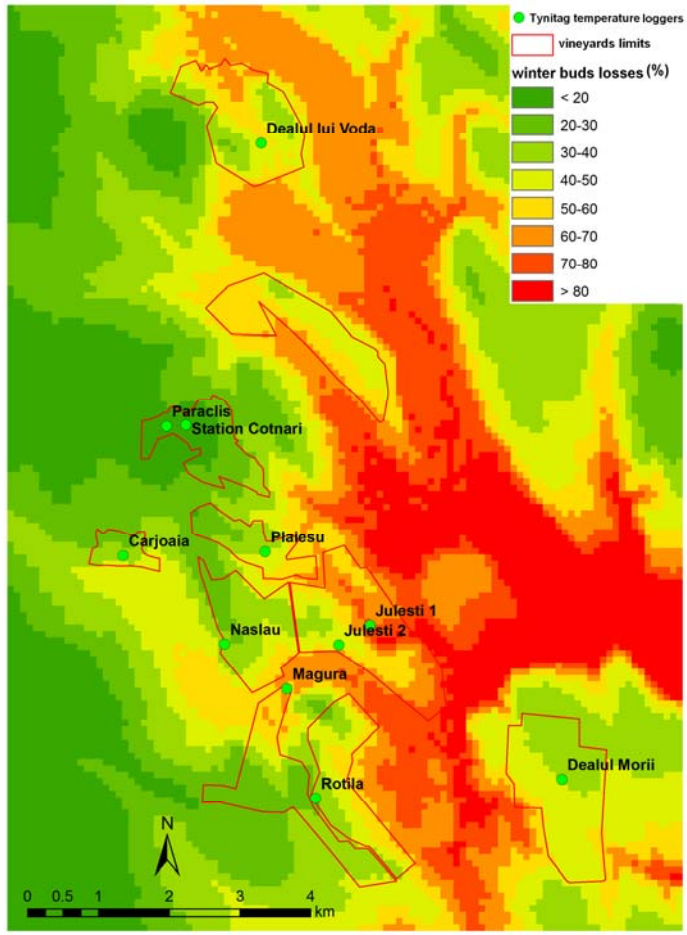

Figure 6 - The spatial distribution of the winter buds losses in Cotnari vineyard, after the frosts from 2011-2012 winter

The analytic data regarding the winter buds losses spatial distribution in the vineyard

The data reveals that the annual branches of vines were destroyed in Juleşti 1 and Măgura lands, in the areas with bud losses highest than 70%, totaling 59.94 ha (3.81% of the total vineyard plantations). The vines were destroyed in the surfaces with bud losses higher than 80%, that represent only 7.29 ha, respectively 0.46% from the total surface of the vineyard plantations *(Table 5)*.

The important local variation of the relief determine the existence in the analyzed area of the micro zones protected by the damaging action of the frosts, along with the exposed ones, where the vines are severely affected by the winter frosts.

CONCLUSIONS

Cotnari vineyard has 1569 ha of vine plantations and is located close enough to the northern limit of vine culture, at 47º20'52" N, 26º56'37" E, in a hilly area, with an important local variation of slopes aspects and altitudes up to 395 m.

In 2011-2012 winter, thermal regime of the vineyard was monitored with ten Tinytag TK-4014 temperature loggers, spread in 10 lands of the vineyard, situated at different altitudes as it follows: Dealul lui Vodă, 150 m; Paraclis, 290 m; Dealul Plăieşului,160 m; Juleşti 1, 116 m; Juleşti 2, 145 m; Naslău, 180 m; Cârjoaia, 168 m; Măgura, 133 m; Rotila, 158 m; Hodora, 153 m.

The 2011-2012 winter was the coldest in the years, temperatures plummeting to -24…-28.6ºC, damaging level for the winter buds, annual branches and even multiannual branches and trunks of the vines.

Data registered with Tinytag temperature loggers shows an important variation of the minimum temperatures in the vineyard, with differences of up to 7.1ºC between Juleşti 1 (the coldest location in the vineyard), and Paraclis (the mildest one), in the day when the absolute minimum temperatures dropped down up to -28.6ºC.

More than 80% from the vine plantations were exposed to temperatures lower than -24º C, 17% to harmful temperatures between -21..-24ºC and 3% to temperatures between -18..-21ºC, less damaging to vines. The only vine plantations protected by frosts were those located at over 175m altitude, in the highest lands of the vineyard.

The damages in the vine plantations varied from no consequences for vines at Paraclis land (17.3-28.2% winter buds losses), up to massive losses of winter buds (67.1-91.6%), major damages of annual branches (32.4-88.1%) and frozen vines (11%) in Juleşti 1 land.

The analytical data of spatial distribution of 12 February 2012 frost shows that: 0.46% (7.29 ha) from the total surface of vine plantations were exposed to vines losses; 3.81% (59.94 ha) of vine plantations to losses of annual branches; 62.49% (980.9 ha) from vine plantations to winter buds losses exceeding 40%, difficult to compensate by pruning; 13.5% (204.9 ha) to losses of winter buds exceeding 60%, requiring reestablishing the vegetative potential of vines.

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