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Full Length Research Paper

Possible application of differential global positioning system (DGPS) to harvesting date and precision viticulture

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From 2004 to 2008, the maturity of grapevine (*Vitis vinifera* L.) was researched on the basis of sugar content and total titratable acidity at six locations with an undulating topography in three varieties: 'Chardonnay', 'Riesling' and 'Sauvignon'. All sampling points were geo-referenced simultaneously with differential global positioning system (DGPS) for creating sugar maps. The significant influence of the varying altitude above sea level (from 389 to 462 m) on the concentration of total sugar and the total titratable acidity of grapes were estimated during the ripeness of vine berry from July to September. The results of a five-year study proved that significant improvement of the grapes quality is possible by creating site-specific maps, which enable separate begging of harvest according to the different sea level.

Key words: Vineyard, sugar map, GIS, DGPS.

INTRODUCTION

Precision agriculture has been described as a continuous cyclical process of data collection, followed by interpretation and evaluation of the information acquired and the implementation of management decisions in response to it (Cook and Bramley, 1998). However, chosen technologies vary greatly depending on demands of individual farms (Blackmore, 1994).

In the last decade, the possibility of precise viticulture was studied only in some particular cases. In order to improve the accuracy of the differential global positioning system (DGPS) location of different machines in the vineyard and creating maps of vine vigour, Tysseyre et al. (1999) developed a map-matching algorithm based on the geo-referenced map. By applying the row and lane position, the accuracy of the location was improved up to 200 cm, which enabled a significant classification of vines.

The implementation of the DGPS technology was also studied in the quality of pesticides spraying distribution in the vineyard (Tiansheng et al., 2001). By positioning of samples of cotton fabrics on the vine tree and leaves, a series of distributes curves and maps were plotted showing a great need for guidance of pesticides and adjusting of the sprayer in the precise viticulture.

A modern geographic information systems (GIS) technology can be applied for the precise measuring of the surface and altitude of any vineyard area. Moreover, it also enables efficient monitoring of all technological processes in the vineyards during growing of grapes such as spraying, cultivating, pruning and harvesting. However, only a few studies have reported possible opportunities of current GPS technology for the production of grapes according to the particular vineyard performances, which influenced different berry yield and its quality.

The grape wine quality and its interaction with yield and soil properties are of greater importance than might occur in arable farming (Bramley and Proffitt, 1999, 2000). Therefore, management strategies need to be developed so both yield and quality can be optimised. The first investigation of relationships between the yield,

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Abbreviations: DGPS, Differential global positioning system; **GIS,** geographic information systems; **SL,** sea level; **SEE,** standard error of estimation.

grape berry quality and soil properties, studied at two vineyards, showed that an improved understanding of the input to the grape production system was required. For mapping of selected soil and vine indices, Bramley (2001) used a modification of the Harvest Master grape yield monitor. In another study, Bramley and Williams (2001) successfully implemented a protocol for grape yield map production for two years in Coonawarra, Australia. However, it was proved that the commercial yield monitoring equipment has not been matched for making useful maps, because of the lack of associated support tools. Thus, it is suggested for wine producers to apply robust methodologies for production of yield map and other vine attributes.

On the other hand, the emergence of the DGPS technology for measuring precisely the effect of altitude, row direction, orientation of the slope and its angle on grape quality has not been investigated, although Horney (1973), Becker (1978), Hoppmann (1978), Hoppmann et al. (1997), Zufferey and Murisier, (1997) and Murisier et al. (2003) already reported the significant affect of the terrain conditions on the heat gain whenever the vines was growing on the terraces. Contrary, Suriano et al. (2009) showed that during the ripening of 'Troia' variety on three different altitudes (150 to 400 m), grapes of low hills reached a sufficient technological maturity and a good phenolic ripeness first; however the grapes of medium hills showed a delay in aging technology with low sugar content and a good polyphenol content.

Regrettably, till now, no comparable research has been conducted in the middle Europe neither in Slovenia, because our holdings are extremely fragmented and most of them are less than five hectares. However, the Slovenian landscape and climate diverse greatly; the variety of climatic (Alpine, Panonian, Mediterranean and transitional) and geological conditions contributes to the use of a wide variety of grapevines and consequently a large assortment of vines in our wine-growing regions.

The eastern Slovenian region includes about 9000 ha of vineyards, with relatively good yields, but the individual vineyards are small too, with very steep slopes that influence times of ripening of grapes. Nowadays, according to the applied technology, the whole area of each vineyard is harvested manually at the same time, thus a substantial loss of quality may result. Namely, as shown for the sub-alpine vineyards by Bertamini et al. (1999), Murisier et al. (2003) and Rusjan (2002), the significant influence of increasing altitude on the sugar content of grapes was detected due to the increasing hours of day sunshine on well exposed south- and west-facing sub-parcels. However, positive correlation was not found for the vineyards lying higher as 550 m.

The main objective of our investigation is to produce a vineyard data base structure needed to explore the possibility of a site-specific determination of optimal maturity of grape berries with respect to the varying altitude of the vines above sea level (SL).

MATERIALS AND METHODS

Site description and sample collection

The area selected for this study was the 20.0 ha Faculty vineyard, Meranovo (Lat = 46° 02' 53.27004" N, Lon = 14° 32' 37.36262" E). The site is divided into four parcels lying on differently oriented terraces and it is roughly 900 m long (east-west) by 650 m wide (north-south). It is characterised by an undulating topography with a difference of 98 m in altitude between the highest (505 m) and lowest point (407 m). As clearly seen from Figure 1, rows of grapes are oriented up and down the south ('Sauvignon'), south-east ('Riesling') and south-west facing slopes ('Chardonnay'). The experiments were performed on the Single Guyot trained grapevines, which were grafted on the 'Kober 5BB' rootstock at 0.9 m spacing and a row spacing of 2.4 m. However, in the past, all rows were oriented across the slope as it can still be noticed in the middle of the old ortho-photo map before the last vineyard reconstruction was conducted two years ago.

For investigating the influence of differences in the height above sea level (SL) on the ripening of grape berries, two rows of three different parcels planted with three varieties 'Chardonnay', 'Riesling' and 'Sauvignon' were selected. As seen from Table 1, all parcels were divided into a 'top' and 'bottom' sub-parcel. Before sampling, the grapes for quality analysis of 25 grapevines were randomly selected and georeferenced from each sub-parcel in the first year, so the same plants were also sampled in the following years.

Then on each sub-parcel, every seven days beginning from end of July till the grape harvest at the end of September, the sugar and acid content of each variety was determined from five samples. Each sample included 200 randomly collected grape berries from 25 grapevines that is, four berries from the sunny side and four berries from the shadow side of each grapevine.

The grape berries were weighed prior to the pressing and the grape juice was later analysed in the laboratory on the content of sugars (deg Brix) refractometrically and total titratable acidity (g/l). The quality analysis including the content of sugars (deg Brix) and total titratable acidity (g/l) were performed to evaluate the effect of SL on the process of ripening, whereas the content of sugar was the most important parameter for the vine producer.

The DGPS measurements data (±0.25 m) were acquired using a GPS receiver CMT MARCH II (Corvallis Microtechnologies Inc.). Additionally, an associated local base-station GPS (GSR1 located in Ljubljana (Slovenia) (Lat = 46° 02' 53.27004" N, Lon = 14° 32' 37.36262" E, h = 351.6585 m) was used to supply differential data to correct the coordinates of the data from the receiver. The ground control location was referenced to a Guass-Krieger projection.

Statistical analysis

For evaluating differences in the sugar and acid content of each grape variety between the top and the bottom sub-parcels, a paired samples t-test were calculated at $P < 0.05$. To examine the relationships between the quality parameters of each grape variety measured at different times during the ripening and the altitude (SL), a linear regression analysis was used. For performing the statistical analysis the Statistical Package for the Social Sciences (SPSS) 14.0 Package Program (SPSS Inc.) was applied.

RESULTS AND DISCUSSION

Sugar content

The maturity of grapevine as well the total sugar content

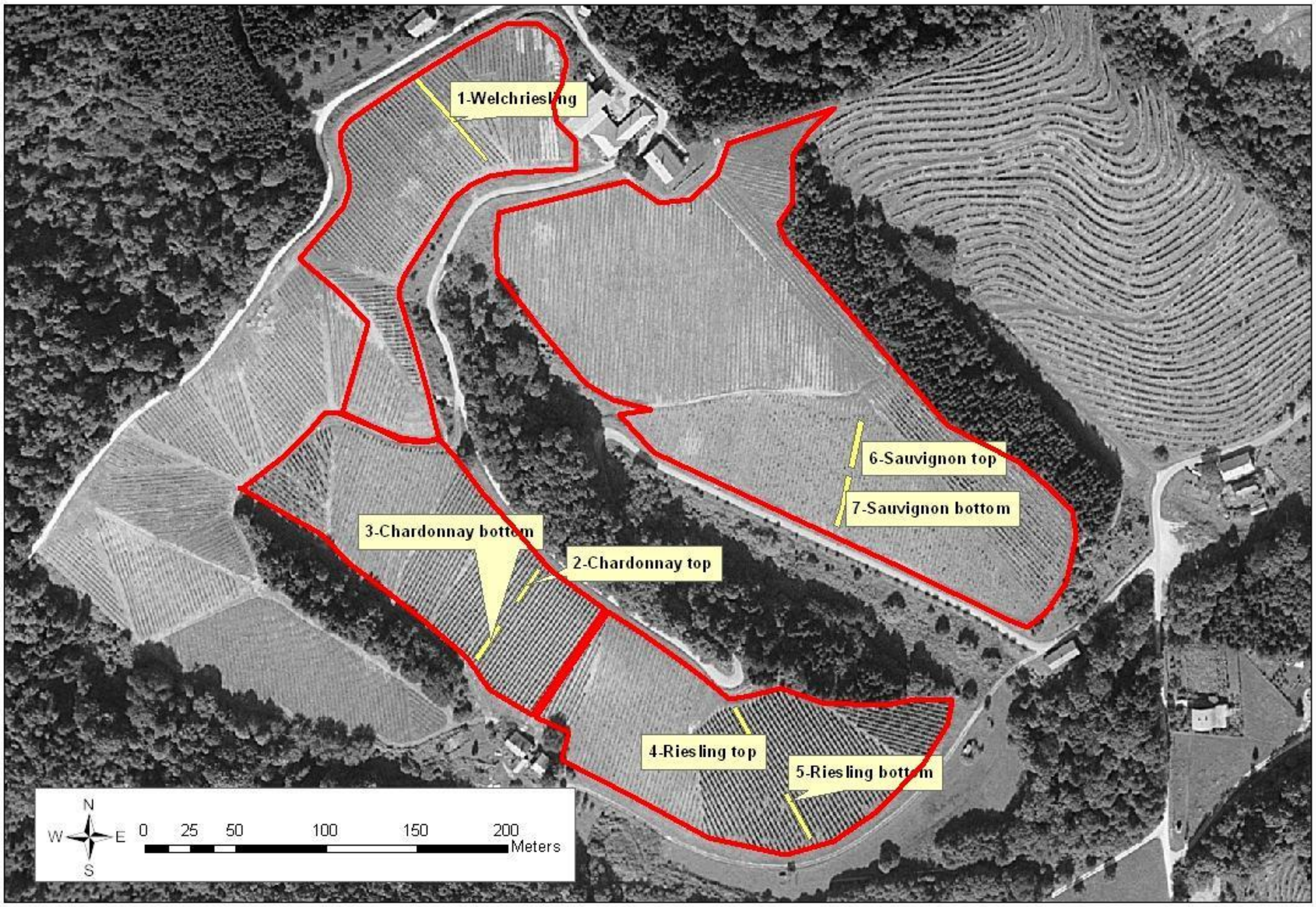

Figure 1. Position of the monitoring locations in vineyards.

Table 1. Data of the experimental parcels.

Location	Variety	Area (ha)	Row orientation	Min altitude (m)	Max altitude (m)	Mean altitude (m)
1	Chardonnay top	0.0055	South-west	450	462	458
2	Chardonnay bottom	0.0061	South-west	432	445	440
3	Riesling top	0.0070	South-east	428	451	435
4	Riesling bottom	0.0076	South-east	395	418	410
5	Sauvignon top	0.0041	South	415	435	423
6	Sauvignon bottom	0.0047	South	389	409	395

varied significantly from year to year depending on the temperature sum during the vegetation and a grape variety. As seen from Figures 2 to 4, the earliest harvest in the experimental period was on September 8th 2005 due to the very hot summer, which effects the shortest vegetation. On the other hand, the longest vegetation was in 2006 with the harvest on October 13th. The highest sugar content in the vine barriers, 22.02 deg Brix, was in 2005 on the sub-parcel 'Sauvignon – top' and the lowest, 16.60 deg Brix, in 2007 on the sub-parcel 'Riesling-bottom'.

Changes of the sugar content (deg Brix) for the selected varieties during all the years are graphically represented in Figures 2 to 4. A paired samples t-test statistics given in Table 2 showed significantly higher values of sugars at the 'Chardonnay' top sub-parcels than from the bottom ones in 2004 and 2008, although also in all other years, the bottom sub-parcels show

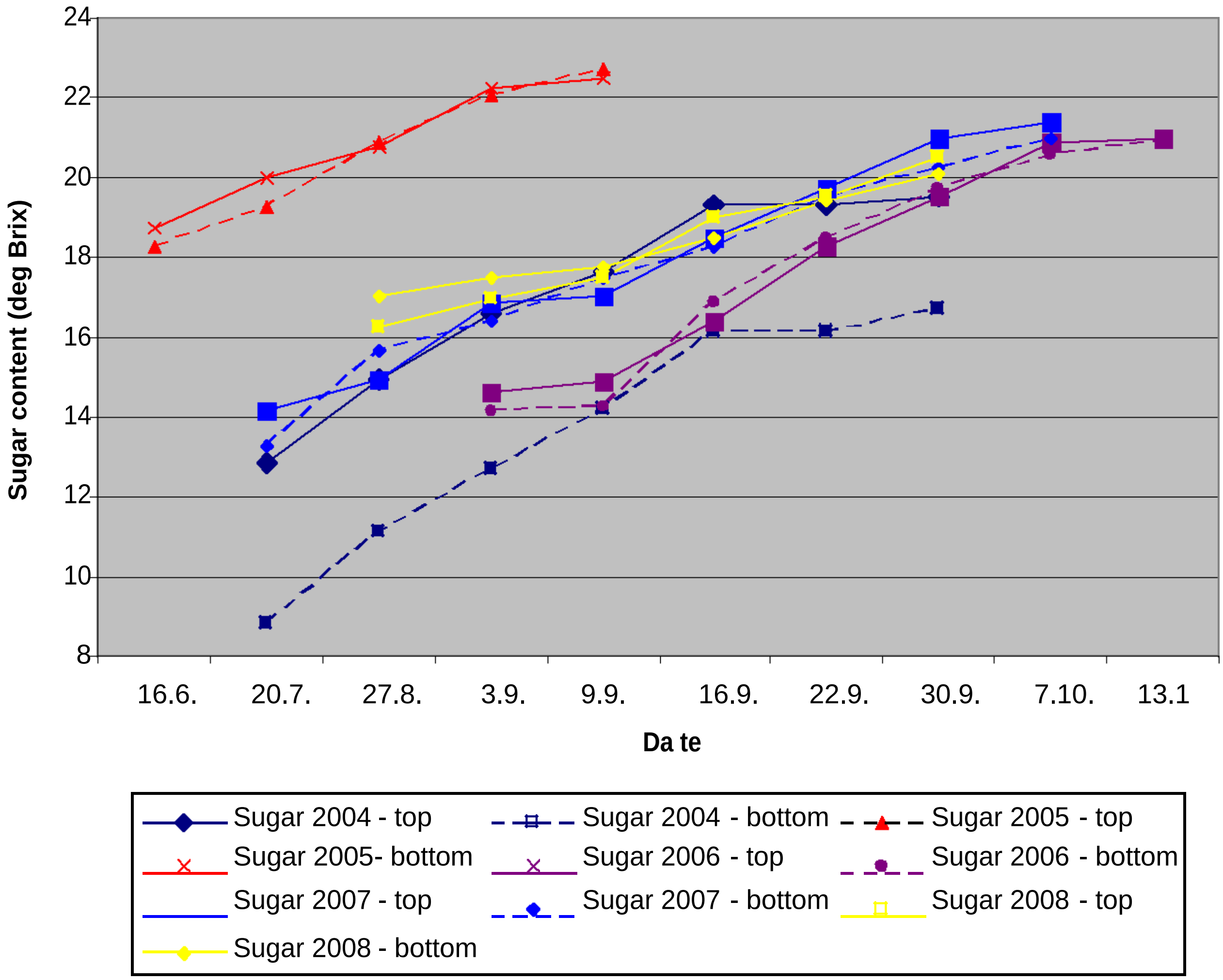

Figure 2. Sugar development in the 'Chardonnay' variety from 2004 to 2008.

affinity for lower values. These results demonstrate the dominant influence of the higher altitude on the temperature sum, which is most important for the ripening process of grape berries.

When looking at the sugar content of the 'Riesling' variety (Table 3), the significant difference between the top and bottom part of sub-parcels was found to be three times that is, in 2004, 2007 and 2008, while in all other years, the sugar content of the bottom sub-parcels showed tendency for lower values.

The values of the sugar content of the 'Sauvignon' variety are presented in Table 4. As seen, the values of the total sugar content in the 'Sauvignon' reached the highest sugar content of all three varieties. Also, in this particular variety the significant higher values was measured on the top part of the sub-parcels in 2004 and 2005, while in all other years the bottom sub-parcels show the trend of lower values. The main reason for differences in the crop maturity between the top and bottom of the sub-parcels was due to the temperature sum differences affected by more sunshine hours on the top part of vineyards. According to Pehar (2000), the significant differences of the sunshine hours were measured in the same vineyards already in 2001, showing the significant influence of air temperature and the relative content of the air moisture. Consequently, leaves and berries of the top part were quickly dried and earlier in the morning, the sugar accumulation was higher. Second explanation was already described by Ziberna (1992) and was known as phenomena of the 'warm thermal belt'. It was the part of the vineyard lying 20 to 30 m above the lowest point of the vineyard influencing the temperature differences in the night between the upper and lower part of vineyards in the eastern Slovenia. However, similar interaction between the slope angle, facing and altitude on one hand and the heat gain on the other was also reported by Bertamini et al. (1999) for vineyards in the Trento region (Italy), Hoppmann (1978) for Rheingau and Baden vineyards in Germany and Murisier et al. (2003) for Ticino (Switzerland). The results of this study are in agreement with Bertamini et al. (1999) who found significant effects of the increased

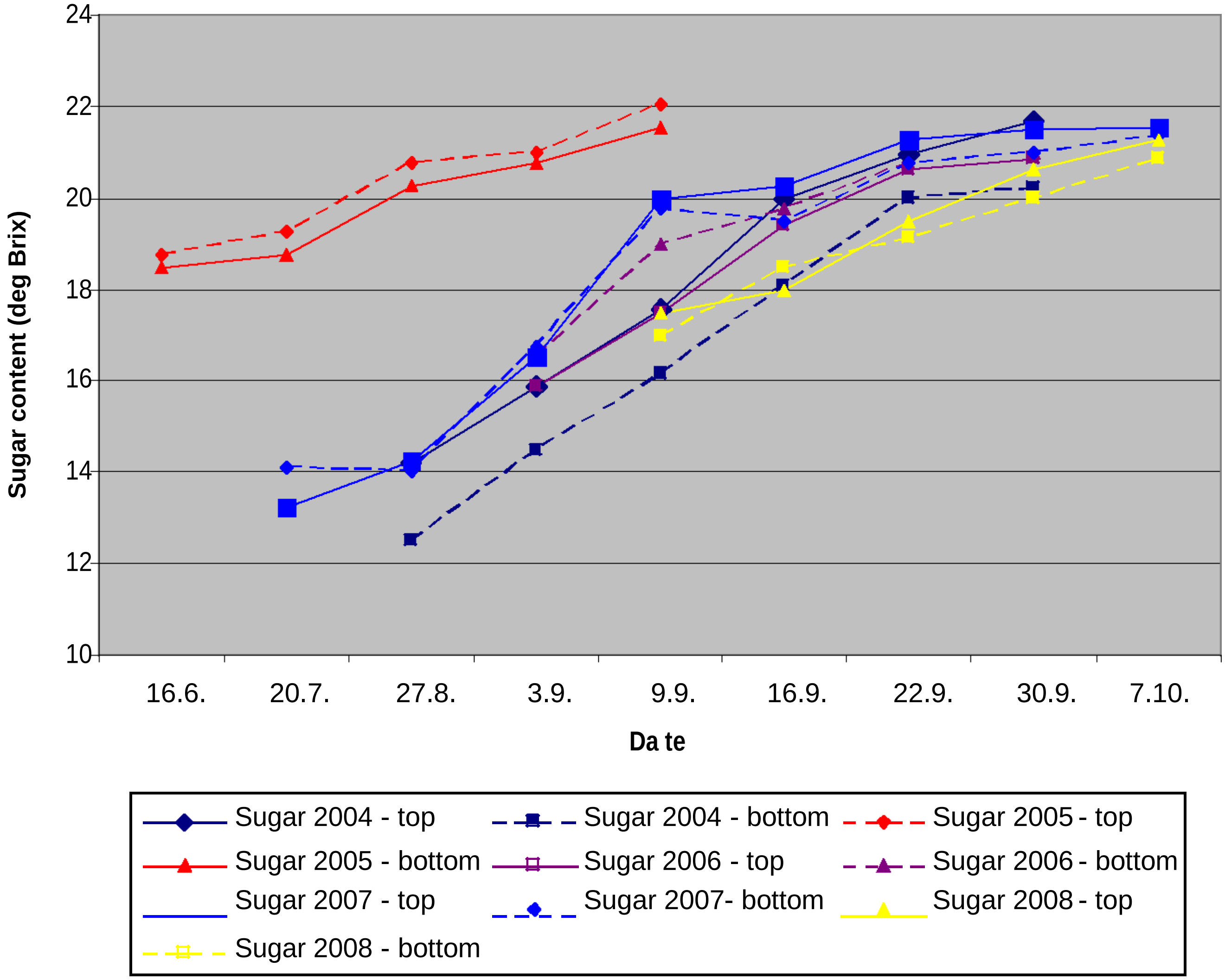

Figure 3. Sugar development in the 'Sauvignon' variety from 2004 to 2008.

altitude on the sugar content in the alpine region of Trentino (Italy).

Titrable acids

Contrary to the sugar content, the total titrable acids (Tables 5 to 7) were significantly higher on the bottom sub-parcels than on the top ones reflecting again the well known changes between the sugar and acidity development during ripening. As seen from the results of the experiments between 2004 and 2008, the acid content was always higher on the 'bottom' sub-parcels, whereby the lowest total amount in the vine barriers (7.60 g/l) was measured in 2005 on the sub-parcel 'Sauvignon - top', while the highest value (17.82 g/l) was detected in 2004 on the sub-parcel 'Riesling – bottom'.

When looking at the total titrable acids of each variety separately, in the 'Chardonnay' (Table 5) there was significant higher content of total acids on the bottom part of the sub-parcels in 2004, 2007 and 2008. Although in all other years, the titrable acids values also showed higher values, there was no difference at $P < 0.05$. In the 'Riesling' variety, the total titrable acids were significantly higher at harvest on bottom sub-parcels in 2006 and 2008 (Table 6), but also in other years, all values showed a tendency for lower values on the top sub-parcels. The total titrable acids for the 'Sauvignon' variety are represented in Table 7. In this particular variety, the total titrable acids were significantly lower on the top sub-parcels than on the bottom ones in the years 2004, 2005, 2006 and 2007.

Sugar and sea level correlation

Further studies of the correlation between the sugar content and the SL in different grapevine varieties are

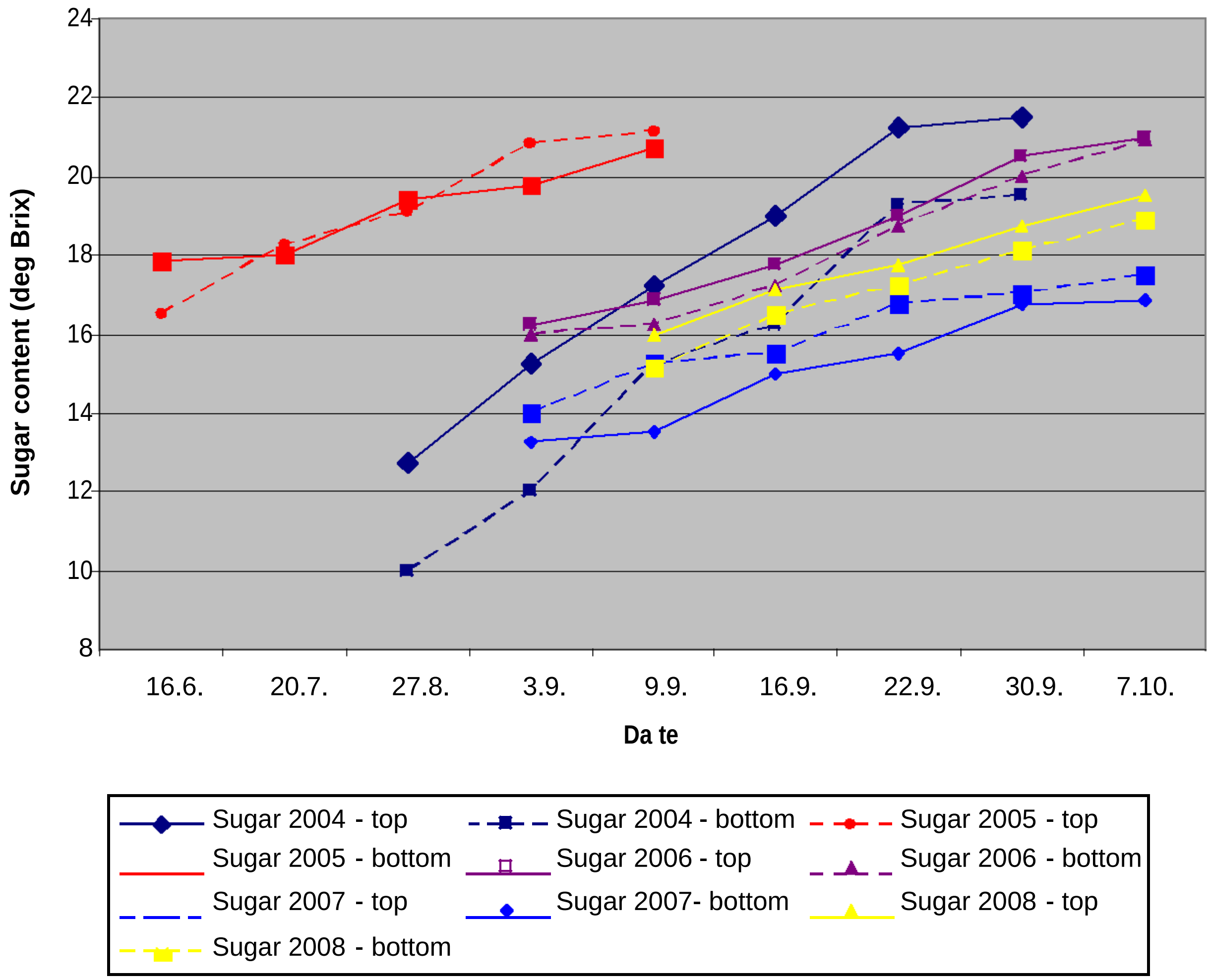

Figure 4. Sugar development in the 'Riesling' variety from 2004 to 2008.

Table 2. Paired sampled statistics for sugar content (deg Brix) of 'Chardonnay' variety.

Year	Paired difference	Descriptive statistic						
		Mean	Mean	Std dev	Std error	Df	t	p
2004	Chardonnay top Chardonnay bottom	19.51 16.72	2.78	0.78	0.22	11	12.33	0.001**
2005	Chardonnay top Chardonnay bottom	22.71 22.50	0.21	0.42	0.19	10	1.104	0.331
2006	Chardonnay top Chardonnay bottom	21.00 20.94	0.06	0.36	0.15	10	0.415	0.695
2007	Chardonnay top Chardonnay bottom	21.37 21.00	0.37	0.27	0.11	10	3.354	0.20
2008	Chardonnay top Chardonnay bottom	20.50 20.10	0.40	0.28	0.12	10	3.138	0.035*

* Significant at P < 0.05, **significant at P < 0.001.

presented in Table 8. As seen, a linear model was developed for each variety and the harvesting year separately, showed very close correlation between the increasing SL and the total sugar quantity in the berries. The standard error of estimation (SEE) as the most reliable characteristics for comparing different models

Table 3. Paired sampled statistics for sugar content (deg Brix) of 'Riesling' variety.

Year	Paired difference	Descriptive statistic						
		Mean	Mean	Std dev	Std error	Df	t	p
2004	Riesling top Riesling bottom	21.25 18.88	2.45	0.53	0.21	11	11.27	0.001**
2005	Riesling top Riesling bottom	21.13 20.71	0.42	0.41	0.18	10	2.26	0.087
2006	Riesling top Riesling bottom	21.00 20.90	0.10	0.72	0.32	10	0.31	0.772
2007	Riesling top Riesling bottom	17.50 16.60	0.90	0.60	0.26	10	3.343	0.029*
2008	Riesling top Riesling bottom	19.50 18.85	0.65	0.13	0.06	10	10.614	0.001**

* Significant at $P < 0.05$, **significant at $P < 0.001$.

Table 4. Paired sampled statistics for sugar content (deg Brix) of 'Sauvignon' variety.

Year	Paired difference	Descriptive statistic						
		Mean	Mean	Std dev	Std error	Df	t	p
2004	Sauvignon top Sauvignon bottom	21.96 20.23	1.46	0.44	0.13	11	11.40	0.001**
2005	Sauvignon top Sauvignon bottom	22.02 21.63	0.39	0.13	0.59	10	6.653	0.03*
2006	Sauvignon top Sauvignon bottom	21.30 20.89	0.41	0.74	0.33	10	1.241	0.283
2007	Sauvignon top Sauvignon bottom	21.55 21.22	0.33	0.34	0.13	10	2.390	0.062
2008	Sauvignon top Sauvignon bottom	21.25 20.98	0.27	0.44	0.19	10	1.380	0.24

*Significant at $P < 0.05$, **significant at $p < 0.001$.

Table 5. Paired sampled statistics for total titratable acidity (g/l) of 'Chardonnay' variety.

Year	Paired difference	Descriptive statistic						
		Mean	Mean	Std dev	Std error	Df	t	P
2004	Chardonnay top Chardonnay bottom	12.60 15.45	-2.85	1.73	0.71	11	-4.018	0.01**
2005	Chardonnay top Chardonnay bottom	7.76 8.14	-0.38	0.65	0.29	11	-1.293	0.266
2006	Chardonnay top Chardonnay bottom	10.83 11.17	-0.33	0.37	0.15	10	-2.233	0.076
2007	Chardonnay top Chardonnay bottom	10.42 11.44	-1.02	0.48	0.22	10	-4.723	0.009**
2008	Chardonnay top Chardonnay bottom	10.92 11.34	-0.42	0.32	0.14	10	-2.941	0.042*

*Significant at $P < 0.05$, **significant at $P < 0.001$.

Table 6. Paired sampled statistics for total titratable acidity (g/l) of 'Riesling' variety.

Year	Paired difference	Descriptive statistic						
		Mean	Mean	Std dev	Std error	Df	t	p
2004	Riesling top Riesling bottom	14.67 17.82	-3.15	1.31	0.35	13	-8.990	0.001**
2005	Riesling top Riesling bottom	7.86 7.96	-0.10	0.75	0.34	10	-0.297	0.781
2006	Riesling top Riesling bottom	11.02 13.14	-2.44	1.54	0.69	10	-3.542	0.02*
2007	Riesling top Riesling bottom	10.08 11.36	-1.28	0.76	0.35	10	-3.644	0.22
2008	Riesling top Riesling bottom	9.84 10.82	-0.98	0.66	0.29	10	-3.334	0.029*

* Significant at P < 0.05, **significant at P < 0.001.

Table 7. Paired sampled statistics for total titratable acidity (g/l) of 'Sauvignon' variety.

Year	Paired difference	Descriptive statistic						
		Mean	Mean	Std dev	Std error	Df	t	p
2004	Sauvignon top Sauvignon bottom	12.28 16.68	-4.40	1.54	0.64	11	-6.822	0.01**
2005	Sauvignon top Sauvignon bottom	7.60 8.18	-0.58	0.43	0.19	10	-3.040	0.038*
2006	Sauvignon top Sauvignon bottom	9.64 10.48	-0.84	0.55	0.25	10	-3.384	0.028*
2007	Sauvignon top Sauvignon bottom	11.90 12.85	-0.95	0.59	0.24	10	-3.950	0.011*
2008	Sauvignon top Sauvignon bottom	10.44 10.48	-0.04	0.71	0.32	10	-0.125	0.906

*Significant at P < 0.05, **significant at P < 0.001.

varied from the highest (1.95 Brix) in 'Riesling 2004' to the lowest (0.58 Brix) in 'Chardonnay' 2008. The model for harvesting in 2004 seems to be most inaccurate, probably due to some unevenness during sampling as it was the first year of our experiment. In all other harvestings, the SEE decreased in all varieties and reached the lowest values in the last 2008 year. When looking at the liner models for each variety separately, the strongest correlation (R^2_{adj} = 0.825) was found in 2006 for 'Riesling' as well for the 'Chardonnay' (R^2_{adj} = 0.815), while for 'Sauvignon' the highest correlation was estimated in 2007 (R^2_{adj} = 0.815). The main explanations for close correlations between the SL and the total sugar content may be found in the rather steep hills in our vineyards, which obviously affect the temperature increase and subsequently the rising temperature sum.

Since the grapes quality is not depended just on the altitude and the sum of temperatures, our linear models can not be used for estimating the sugar content at harvest in the specific year, but serve only as a tool for showing the correlation between the altitude and total sugars of the particular grapevine variety.

Conclusions

The proposed geo-referenced monitoring technique based on the DGPS data measurements can be effectively employed to provide objective information on the ripening process of white grape wines which were grown at varying altitude above sea level.

In five experimental years (2004 to 2008), the system was tested successfully during the ripening period (August to October) for monitoring the total sugar content and total titrable acids of three different grapevine varieties that is, 'Chardonnay', 'Riesling' and 'Sauvignon'. In all our cases, when the difference between the top and bottom part of the sub-parcel was over 18 m, the sugar content was significantly higher on the top part of the parcel than on the bottom one, while the total titratable

Table 8. Regression between sugar content (Brix) and sea level in three grapevine varieties during the ripening in the experimental period 2004 to 2008.

Year	Variety	Linear model			
		Intercept	Slope	R^2_{adj}	SEE (Brix)
2004	Chardonnay	-109.94**	0.29**	0.604*	1.12
	Riesling	-71.57**	0.208**	0.713*	1.95
	Sauvignon	-50.91**	0.167**	0.707*	1.32
2005	Chardonnay	-44.58**	0.147**	0.71*	0.69
	Riesling	19.76*	0.086**	0.743*	0.77
	Sauvignon	38.42*	0.044	0.599*	1.11
2006	Chardonnay	-.67.99*	0.194**	0.812*	0.78
	Riesling	-30.05*	0.11**	0.825*	0.78
	Sauvignon	-23.63**	0.104*	0.690*	0.69
2007	Chardonnay	-77.06**	0.215*	0.815*	0.96
	Riesling	-15.55*	0.07*	0.670**	0.75
	Sauvignon	-27.93*	0.11**	0.709**	1.13
2008	Chardonnay	-38.13**	0.13**	0.722**	0.58
	Riesling	-15.27*	0.77**	0.642**	0.69
	Sauvignon	-12.01*	0.75*	0.665**	0.74

* Significant at $P < 0.05$, **significant at $P < 0.01$.

acidity was lower. The results of the research indicated that in the future, sugar maps could form the basis for forecasting an optimal harvesting time, separately, for different parts of the vineyards lying on the extremely steep slopes.

However, the enhanced and complex understanding of the interaction between the altitude and the specific vineyard is necessary to adopt the site specific determination of optimal grape harvest successfully. Thus further work is needed to study these particular cases also in other growing areas.

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