SOILCONS-WEB PROJECT

Technical paper: Adaptive capacity of a viticultural area (Valle Telesina) to climate changes

INTRODUCTION

Understanding the effects of climate change in the areas traditionally vocated to vineyard production allows to assess the future viability of current cultivation.

There are many pedo-climatic factors that affect vineyard production, as described by Carey, 2001 by means of the "terroir" concept, i.e. a complex of natural environmental factors, which cannot easily be modified by the producer.

The large influence of climate on vine growth and in determining the character of the wine was discussed in detail by Saayman, 1977 and Carey, 2001, among others.

The effect of soil water availability on vine functioning and on grape and wine quality is of established importance (e.g. Matthews and Anderson, 1988; Medrano *et al*., 2003).

The assessment of the influence of climate change on vineyard production can rely upon the availability and the combination of research tools like raster GIS (Bonfante *et al*., 2005; Scaglione *et al*., 2008; Acevedo-Opazo *et al*., 2008), DEM derived analysis (MacMillan *et al*., 2000), hydrological simulation models (Ben-Asher *et al.*, 2006), global and regional climate simulation models (Jones *et al.*, 2005).

The main aim of the present work is to evaluate, in a viticultural area of Southern Italy, the effects of a climate variation on the thermal regime and on the distribution of the cultivation area of different grape cultivars.

MATERIALS AND METHODS

The study area: environmental dataset

The work has been performed in "Valle Telesina", a 20.000 ha complex landscape located in the Campania region, Southern Italy. The area has a high soil and climate spatial variability; it is a traditional setting for vineyards producing high quality wines, including three DOC wines (Guardiolo, Solopaca and Sannio).

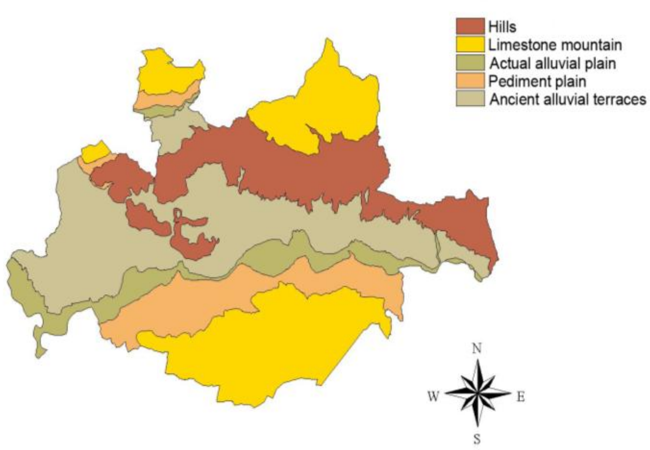
The landscape has a complex geomorphology and it is characterized by an E-W elongated graben where the Calore river flows. The area shows five different geomorphic environments (Fig.1), namely (i) limestone mountains having volcanic ash deposits at the surface; (ii) hills constituted by marl arenaceous flysch; (iii) pediment plain constituted by colluvial material of the slope fan of the limestone relieves; (iv) ancient alluvial terraces and (v) actual alluvial plain.

Soil information were derived from a soil map at 1:50,000 scale (Terribile et al., 1996) consisting of 47 soil mapping units and about 60 soil typological units. In this work 32 of 47 soil units were used, covering almost completely the area.

The digital elevation model (DEM) was obtained from the digitalization of topographic maps, produced by the Istituto Geografico Militare Italiano at 1:25,000 scale, producing a DEM having a 20×20 m resolution.

The climatic data were obtained from Campania Region agrometeorological office and refer to two climatic periods: 1984-1996 and 2000-2009 ("past" and "present" period, respectively).

Fig.1 - The main geomorphic environments of "Valle Telesina".



The spatial distribution of mean air temperature was derived as reported by Bonfante at al. (2005). Data of 12 weather stations located at different altitudes, inside and in the near surroundings of the study area, were used. The spatial distribution of mean daily air temperature was obtained by means of a simple regression function among elevation and temperature.

Daily reference evapotranspiration (ETo) was evaluated according to the equation of Hargreaves (Hargreaves, Samani, 1985).

Thermal index of Amerine & Winkler (A&W)

The thermal index of Amerine & Winkler, 1944, is the sum of average daily temperature, accounting for the thermal level at which no growth occurs, calculated in the period between 1 April and 31 October:

$$I(DD) = \sum_{1/04}^{31/10} (T_m - 10) \qquad [1]$$

where I is the A&W thermal index value expressed in degree day (DD), Tm is the average daily temperature and 10 is a constant representing the zero vegetative of grapevine.

Through the daily temperature data spatially distributed, the A&W thermal index was calculated for the whole study area. In order to calculate the A&W index in each point of the "Valle Telesina" 214 matrices of daily temperature (one matrix per day, from 1 April to 31 October) were built for each climatic period. The differences between the index's values in 2000-2009 versus 1984-1996 period were computed.

The thermal needs of grape varieties of the study area were taken from Scaglione et al., 2008.

Hydrological modelling

Soil water balance simulation was performed using the Soil–Water–Atmosphere–Plant (SWAP) model (Kroes, van Dam, 2003). This application enables to estimate the components of the water balance at daily time dynamics. Assuming 1-D vertical flow processes, the model calculates the water flow in the soil matrix through the Richards' equation , taking into account root water extraction by an additive term.

Soil water retention and hydraulic conductivity curves were described by the van Genuchten-Mualem expression (van Genuchten, 1980) and their parameters were derived applying the pedo transfer function HYPRES (Wösten et al., 1998) whose reliability was tested and validated on three soils of the same area. Upper boundary condition data were derived from weather dataset and unit gradient in hydraulic head was set as lower boundary condition.

SWAP model runs were applied for to calculate crop actual and potential transpiration in the 32 soil units.

Crop Water Stress Index (CWSI)

The CWSI is often defined as:

$$CWSI = \left[1 - \left(T_{act}/T_{pot}\right)\right] \cdot 100 \qquad [2]$$

where Tact/Tpot is the ratio between actual and potential transpiration.

In the present work Tact and Tpot were calculated daily by the SWAP model applying crop-specific input data (Allen et al., 1998; Kroes, Van Dam, 2003).

The vineyard CWSI was estimated in the climatic period 2000-2009; the cumulated Crop Water Stress Index (CWSIcum) was calculated summing CWSI (eq. 2) in the period from shooting (1 April) to harvest (15 September). The results were averaged over the ten year period, a map of the CWSIcum was thus derived.

RESULTS AND DISCUSSION

Thermal index of Amerine & Winkler

The difference in mean daily temperature between the “present” and the “past” climatic period was 1.4 °C.

The values of the A&W indexes of the periods are shown in Tab. 1.

Tab. 1 Amerine and Winkler indexes (DD)

climatic period	max	min	avg
1984-1996 (“past”)	1870	737	1657
2000-2009 (“present”)	2140	849	1866

The maximum and minimum differences of the index’s values in the two periods resulted 270 and 110 DD, respectively. Fig. 2 shows the spatially distributed differences of A&W index between the two climatic periods. The differences in the index values were higher than 220 DD in a preponderant part of the study area; in the limestone mountain zone the differences were smaller.

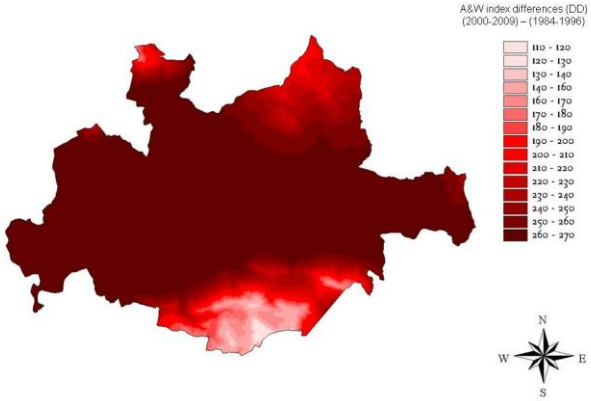


Fig. 2 – Map of the Amerine and Winkler index differences between the "present" (2000-2009) and the "past" (1984-1996) climatic periods.

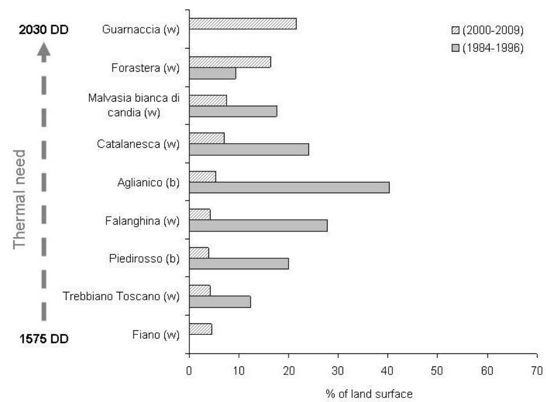


Fig. 3 – Local grape *cvs* suitable surface (%) in the "past" and "present" climatic periods.

The A&W index of the two climatic periods, spatially distributed in the study area, was compared with the heat requirements of local grapevine varieties (Scaglione et al., 2008) and results are reported in Fig. 3. In the "present" period the thermal regime allowed the increase of the land surface suitable for Forastera, a variety with rather high thermal requirements (1950 DD) and Guarnaccia, a variety whose thermal needs were not met in the "past". The latter, in the warmer "present" period, would have the largest suitable cultivation area (21 % of the entire "Valle Telesina"). Conversely, the difference in thermal regime between "present" and "past" determined a strong reduction of the area eligible to Aglianico and Falanghina, two of the most important current black (b) and white (w) varieties; moreover it can be supposed that Aglianico and Falanghina would move towards areas at higher altitude.

If the temperature trend from the "past" to the "present" period will be confirmed as a long-term trend in the area, the adaptability of grapevine production will have to rely on a larger use of different, and possibly new, grape cvs.

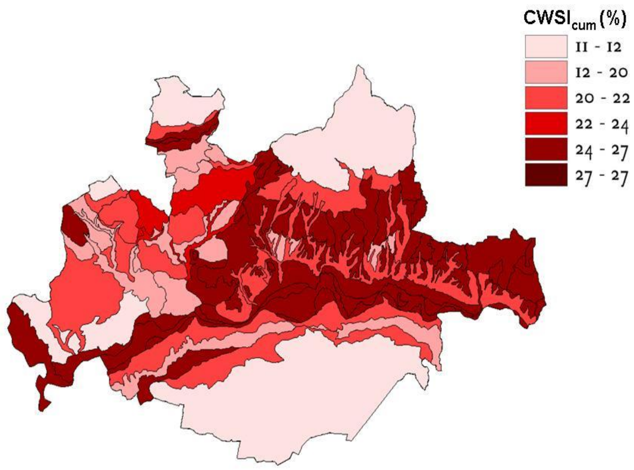


Fig. 4 – Map of the $CWSI_{cum}$ values, cumulated from shooting to harvesting, and averaged over the "present" climatic period.

Crop Water Stress Index (CWSI)

Further analysis was conducted by means of the SWAP hydrological simulation model to estimate functional properties relevant to vineyard production. Specifically, the $CWSI_{cum}$ values were calculated and spatially distributed over the study area (Fig. 4). The minimum $CWSI_{cum}$ value (10.5 %) was found in the limestone mountains (see Fig. 1) and the maximum value (27.5 %) occurred in the pediment plain. The maximum $CWSI_{cum}$ corresponds to a T_{act}/T_{pot} ratio of 0.73. Trambouze and Woltz, 2001 measured a similar value of the ratio when 2/3 of soil water storage was depleted. The maximum $CWSI_{cum}$ value therefore indicated a significant plant water shortage. Moreover, the results show a quite high variability of $CWSI_{cum}$ in the whole study area.

CONCLUSIONS

The effects produced by climate change on potential vineyard distribution over an inland area of Southern Italy ("Valle Telesina") were analyzed. The different climatic pattern between two periods ("past" 1984-1996 and "present" 2000-2009) was assumed to be an example of future trends generated by climate changes.

The different thermal regime between the two periods was translated into differences in A&W indexes' values; moreover the distribution of the Crop Water Stress Index was assessed for vineyards in the "present" climate.

The match between thermal regime and requirements of local cultivars allowed to assess a redistribution: traditional and widely distributed Falanghina and Aglianico would have a smaller area with favourable environment; whereas the extension of the area of cvs Forastera and Guarnaccia, the latter not cultivated in the "past" climate, would increase.

An interplay between the re-distribution of cultivars and the pattern of CWSIcum over the study area would cause different consequences on vines' physiological processes, and therefore, on quantity and quality of production. The analysis could be further detailed to examine the effects of thermal and water regimes occurring at different phenological phases.

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REFERENCES

Acevedo-Opazo C., Tisseyre B., Guillaume S., Ojeda, H., 2008. The potential of high spatial resolution information to define within-vineyard zones related to vine water status. Precision Agric., 9:285-302.

Allen R., Pereira L.S., Raes D., Smith M. 1998. Crop evapotranspiration – Guidelines for computing crop water requirements. *FAO Irrigation and Drainage Paper*, vol. 56, Rome, Italy.

Amerine M.A., Winkler A.J., 1944. Composition and quality of must and wines of California grapes. *Hilgardia*, 15: 493-675.

Bonfante A., Basile A., Buonanno M., Manna P., Terribile F., 2005. Un esempio metodologico di utilizzo della modellistica idrologica e delle procedure GIS nella zonazione viticola. *Bollettino della Società Italiana della Scienza del Suolo* (SISS), 54: 1-2.

Ben-Asher J., van Dam J., Feddes R.A., Jhorar R.K., 2006. Irrigation of grapevines with saline water II. Mathematical simulation of vine growth and yield. *Agric. Wat. Manag.*, 83: 22-29.

Carey V., 2001. Spatial characterization of natural terroir units for viticolture in the Bottelaryberg-Simonsberg-Helderberg wine growing area. *M.Sc. Thesis, Stellenbosch University*, Private Bag X1, 7602 Matieland (Stellenbosch), South Africa.

Kroes J.G., Van Dam J.C., 2003. Reference manual SWAP version 3.0.3. *Alterra, Green World Research*, Wageningen (The Netherlands).

Hargreaves G.L., Samani Z.A., 1985. Reference crop evapotranspiration from temperature. *Applied Engineer. In Agric.*, 1, 2: 96-99.

IPCC, 2007. Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental

Panel on Climate Change. In: Parry M.L., Canziani O.F., Palutikof J.P., van der Linden P.J., Hanson C.E. (Eds.). Cambridge University Press, Cambridge, UK.

Jones G.V., White M.A., Cooper O.R., Storchmann K., 2005. Climate change and global wine quality. *Climatic Change*, 73: 319–343.

MacMillan R.A., Pettapiece W.W., Nolan S. C., Goddard T.W., 2000. Generic procedure for automatically segmenting landforms into landform elements using DEMS, heuristic rules and fuzzy logic. *Fuzzy Sets and Systems*, 113:81-109.

Matthews M., Anderson M., 1988. Fruit ripening in Vitis vinifera L.: responses to seasonal water deficits. *American Journal of Enology and Viticulture*, 39: 313–320.

Medrano H., Escalona J.M., Cifre J., Bota J., Flexas J., 2003. A ten-year study on the physiology of two Spanish grapevine cultivars under field conditions: effect of water availability from leaf photosynthesis to grape yield and quality. *Functional Plant Biology*, 30:607-619.

Saayman D., 1977. The Effect of Soil and Climate on Wine Quality. In: *Proc. International Symposium on the Quality of the Vintage*, Cape Town, South Africa. 197–208.

Scaglione G., Pasquarella C., Federico R., Bonfante A., Terribile F., 2008. A multidisciplinary approach to grapevine zoning using GIS technology: An example of thermal data elaboration. *Vitis*, 47 (2):131-132.

Terribile F., Di Gennaro A., De Mascellis R., 1996. Carta dei suoli della Valle Telesina. Progetto U.O.T. *Relazione finale convenzione CNR-ISPAIM-Regione Campania Assessorato alla Agricoltura.*

Trambouze W., Voltz M. 2001. Measurement and modelling of the transpiration of a Mediterranean vineyard. *Agric. For. Metorol*, 107:153-166.

van Genuchten M. Th., 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Sci. Soc. Am. J.*, 44:892-898.

Wösten J.H.M., Lilly A., Nemes A., Le Bas, C., 1998. Using existing soil data to derive hydraulic properties for simulation models in environmental studies and in land use planning. *Report 156, Winand Staring Centre*, The Netherlands.