IDŐJÁRÁS

Quarterly Journal of the Hungarian Meteorological Service
Vol. 113, No. 1–2, January–June 2009, pp. 69–78

Current trends of agroclimatic indices applied to grapevine in Tuscany (Central Italy)

Simone Orlandini, Valentina Di Stefano, Paolo Lucchesini, Annalena Puglisi, and **Giorgio Bartolini**

Department of Agronomy and Land Management, University of Florence, Piazzale delle Cascine 18, 50144 Firenze, Italy; E-mail: simone.orlandini@unifi.it

(Manuscript received in final form January 15, 2009)

Abstract—Global warming is causing wide changes in atmospheric events with critical impacts on vegetations. Indeed, an increase of temperature variability has been observed, primarily due to increase in warm extremes. Temperature rising will lead to several consequences. For example, growing season lengthening is observed, but at the same time, plants grow faster, thus giving productions low in quality and quantity. Finally, concerning the Mediterranean region, it is evaluated that a greater water request is needed for irrigation. Besides, high maximum temperatures during summer months may cause drop in quality. On the opposite, concerning winter risks, earlier bud break will increase late frost risks. The aim of this study is to cover some aspects of warming temperature and phenological responses on grapevine in central Italy. The research is focused on climatic and agroclimatic indices calculated in 1955–2007 period. Regression trend, linear or non-parametric, depending on the distribution of data, was fitted to provide pictures of changes that have occurred.

Key-words: global warming, climate variability, rising temperature, phenology, quality, frost, *Vitis vinifera*

1. Introduction

A long history of grapevine (*Vitis vinifera*) is associated with the fitoclimatic Mediterranean area. Indeed, famous wine regions were established in this area during the Roman Empire, because it was recognized the fundamental link between the geographic location and the climatologic condition.

Nowadays this idea is the basis of the wine zoning. The wine style produced by regions is the result of the baseline climate, while climate variability determines vintage-to-vintage quality differences (*Jones*, 2003; *Jones* and *Hellman*, 2003). In particular, climate strongly affects the given wine style, because it has a deep influence on the optimum levels of sugar, acid, and flavor on grape. As for global warming, some studies highlight both positive and negative impacts in Europe. Among positive ones, the total surface suitable to cultivation foreseen by climatological models is going to increase and extend to European north latitudes and higher altitudes (*IPCC*, 2007; *Bindi et al*., 2002). On the contrary, in southern areas of Europe, the benefits of the forecasted climate change will be limited, while the disadvantages will be predominant (*Maracchi et al*., 2005). The Mediterranean area, in particular, shows high susceptibility to the most recent increase and variability of temperature: these strongly affect viticultural activities, modifying grapevine responses and determining the quality and quantity of vine production (*Jones* and *Hellman*, 2003). Among the other consequences, rising temperature is going to cause both geographical and varietal changes in grape cultivation (*Orlandini*, 2004).

As regard crops quality risks, high temperature and dry condition, especially in September, can be critical for grape quality, because they cause excessive fruit ripening, affecting fruit quality (*Schultz*, 2000).

Moreover, as for the impacts on the physiology, a few case studies point out that rising temperature in this area determines increase of water request and needs of monitoring. Indeed, even if grapevine is quite resistant to high summer temperature and drought, the increase of extreme conditions can be responsible of physiological stresses, such as the reduction of photosynthetic efficiency.

Concerning the phenology, higher minimum temperatures activate cellular split (*Nemani et al*., 2001), thus causing advanced harvest. Moreover, a study conducted in the north-east part of Italy during the 1956–2002 period, shows an increase of thermal sum that determines earlier phenological phases (*Puglisi et al.*, 2005).

One of the most important indices used to investigate plant phenology is the growing season starting date, that is strongly related with air temperatures (*Fregoni*, 2002). For example, it is recently largely observed that a positive anomaly on the temperature trend during the growing season determines grape phases shift, with negative effect on vine quality. Indeed, it leads to the premature change of color, sugars accumulation, and partial or total failure of flavor ripening (*Mullins et al*., 1992), in some cases enzyme inactivation (*Jones et al*., 2005).

Moreover, the increase of interannual variability in temperature and precipitations makes adaptation to such continuous changes very expensive, thus winemakers have to be flexible in viticulture techniques planning and management beyond rescheduling crop operations (*Bindi et al*., 2002). A study on Sangiovese and Cabernet Sauvignon in Italy revealed that warmer conditions will lead to shorter growth range and higher yield variability (*Bindi et al*., 1996).

Finally, the more delicate grapevine growth phases, such as the very early ones, will be more and more vulnerable. In particular, bud-break will be affected by the late frost risk increase (*Nemani et al*., 2001).

Assessment of the potential impacts of climate change on viticulture is demanded by scientists, policy makers, producers, and others to make decisions on policies and management practices that may minimize negative impacts and take advantage of positive impacts or opportunities.

On these bases, this study analyzes some climatic and agroclimatic indices trend to assess temperature changing and the consequent potential impacts on grapevine cultivation in Tuscany (central Italy).

2. *Material and method*

From a meteorological network, 22 stations were selected in Tuscany, Italy, for the 1955–2007 period (*Table 1*; *Fig. 1*). The following criteria were adopted to select stations: first, low percentage of missing data, because even if the techniques to reconstruct the series are known, it is preferable to start the analysis with original data; second, a long period covered by dataset, thirty years at least. Finally, stations must be distributed all over the territory to have a complete overview of the climate in Tuscany.

Table 1. Geographical information of the meteorological stations

Meteorological station	**UTM_X (m)**	**UTM_Y (m)**	**Altitude (m a.s.l.)**
Arezzo	730805	4815384	249
Boscolungo	633977	4888891	1340
Camaldoli	727025	4853030	1110
Castel del Piano	706920	4752060	596
Castelnuovo Garf.	613275	4885305	280
Elba Calamita	614306	4731893	380
Firenzuola	689640	4888022	454
Grosseto	669415	4735216	5
Livorno	606140	4822595	9
Lucca	620990	4855580	25
Massa	591800	4875450	38
Massa Marittima	653850	4768500	362
Montepulciano	726520	4774950	575
Orbetello	681025	4699970	1
Peretola	676985	4852101	38
Pisa	613017	4838671	3
Pistoia	653080	4867535	88
Pontremoli	570117	4913436	247
San Miniato	647740	4838630	132
Siena	687630	4799185	346
Vallombrosa	706000	4845450	972
Volterra	649965	4808235	465

Fig. 1. Meteorological station distribution in Tuscany.

In the first place, the dataset (period of 1955–2007) was verified as the GCOS (Global Climate Observing System) recommends: in order to avoid inhomogeneities or discontinuities in the climate record (caused by changes to the station, such as site location and instrumentation), time series were homogenized through the method described in *Brunetti et al*. (2006). After that, basic data exploration was carried out, considering absolute values and then differences between contiguous day values. Suspect values were coded as NA (not available). If neighboring stations with well correlated data were available, original suspect ones were reconstructed by statistical process. Afterwards, climatological mean and extreme temperature indices were selected in order to analyze climate and climatic variability. Climatic temperature indices were mean minimum (TN) and mean maximum temperature (TX). These indices were calculated both on seasonal and annual time scale. Extreme temperature indices were split in summer and winter and calculated only on the season when they showed effects. The summer period included June–August while winter period consisted in December–February. Selected summer extreme temperature indices were warm days and warm nights (*Manton et al*., 2001; *Peterson et al*., 2001; *Klein Tank* and *Können*, 2003; *Bartolini et al.*, 2008). For the winter period number of cold nights and number of days with minimum temperature lower than 0 °C (FD) were selected.

Concerning the potential impacts of climate change on grapevine, they were detected by applying agroclimatic indices such as growing degree days (GDD) related to the starting date of the most important phenological phases (bud-break, flowering, ripening) and expressed in doy (day of the year); length of growing season with 0 °C threshold (VGS0), thermal summation with 10 °C threshold in the period March–September (STA10), thermal summation with 10 °C threshold in the period April–October (STA10 Winkler), and Huglin index. These are good indicators of the interactions between climate trend and the physiological needs. In fact, to detect bud break trigger it must be considered that each species need a specific heat quantity to activate the phenological stages. Huglin index, as GDD index, is used in viticulture to explain temperature availability in a specific area. In particular, high values of this index reveal suitable areas for grapevine with late maturation, while low values fit for early maturation varieties. Huglin index is estimated by making use of maximum and mean daily temperatures. *Table 2* shows all the selected indices with the acronyms.

Table 2. Climatic and agroclimatic indices

Acronym	Unit	Description
TN (a)	°C	Mean of minimum temperature (annual)
TN (sp)	°C	Mean of daily minimum temperature (spring: March–May)
TN (s)	°C	Mean of daily minimum temperature (summer: June–August)
TN (au)	°C	Mean of daily minimum temperature (autumn: September–November)
TN (w)	°C	Mean of daily minimum temperature (winter: December–February)
TX (a)	°C	Mean of daily maximum temperature (annual)
TX (sp)	°C	Mean of daily maximum temperature (spring: March–May)
TX (s)	°C	Mean of maximum temperature (summer: June–August)
TX (au)	°C	Mean of maximum temperature (autumn: September–November)
TX (w)	°C	Mean of maximum temperature (winter: December–February)
TN90p*	°C	Number of days with daily minimum temperature higher than 90 percentile (1961–1990) calculated in summer period (July–August)
TX90p*	°C	Number of days with daily maximum temperature higher than 90 percentile (1961–1990) calculated in summer period (July–August)
FD (a)	Days	Annual number of days with minimum temperature lower than 0 °C
GDD Bud break	Day	Date of bud break: It is the doy (day of the year) when the summation of the differences between the mean daily temperature and the threshold temperature (10 °C) reaches a specific value
GDD Flowering	Day	Date of grape flowering: It is the doy (day of the year) when the summation of the differences between the mean daily temperature and the threshold temperature (10 °C) reaches a specific value
GDD Ripening	Day	Date of grape ripening: It is the doy (day of the year) when the summation of the differences between the mean daily temperature and the threshold temperature (10 °C) reaches a specific value
HI	Degrees	Huglin index: Daily summation of the mean between maximum and mean temperature calculated during the growing season (March-September) multiplied by a latitude coefficient
STA10	°C	Thermal summation (10 °C threshold): Daily mean temperature summation in the growing period (March–September)
STA10 Winkler	°C	Thermal summation (10 °C threshold): Daily mean temperature summation in the growing period (April–October)
VGS0	Days	Vegetative growing season (0 °C threshold): Number of days between the last and first frost events of the year

Data were analyzed to test the normality of the distribution with the Shapiro-Wilk normality test. If normal, the linear trend was fitted, otherwise the Theil-Sen (*Theil*, 1950; *Sen*, 1968) non-parametric test was applied.

Parametric and non-parametric regression was fitted to each index and meteorological station. Regression slope was evaluated in order to detect trends and changes occurred over the considered period.

3. *Results*

Table 3 shows all the results for each analyzed index. Climatic temperature indices (TN and TX) show a tendency to increase. In particular, the increase of annual maximum temperature (+0.9 °C/50 years) was similar to that of minimum temperature. Seasonal analysis shows a much greater increase of minimum and maximum temperatures in summer (+1.5 °C/50 years; +1.7 °C/50 years, respectively) and spring season (+0.9 °C/50 years and +1.1 °C/50 years, respectively).

Table 3. Trends of the climatological indices of the 22 meteorological stations (1955–2007)

S	Index	n°	n	N°	NN°	m	m1	m*	m1*
22	TN (a)	22 ; 0	0	20 ; 0	19 ; 0	+0.8		+0.9	
22	TN (sp)	21 ; 1	0	12 ; 0	10 ; 0	+0.9		+1.1	
22	TN (s)	22 ; 0	0	20 ; 0	20 ; 0	+1.5		+1.6	
22	TN (au)	18 ; 4	0	6 ; 0	5 ; 0	+0.6		+1.3	
22	TN (w)	20 ; 2	0	4 ; 0	2 ; 0	+0.5		+1.8	
22	TX (a)	22 ; 0	0	21 ; 0	21 ; 0	+0.9		+0.9	
22	TX (sp)	22 ; 0	0	16 ; 0	15 ; 0	+1.1		+1.3	
22	TX (s)	22 ; 0	0	22 ; 0	21 ; 0	+1.7		+1.7	
22	TX (au)	16 ; 6	0	1 ; 1	0 ; 1	+0.1		–1.3	
22	TX (w)	22 ; 0	0	6 ; 0	5 ; 0	+0.9		+1.2	
22	TN90p *	22 ; 0	0	20 ; 0	20 ; 0		+1		+18
22	TX90p *	22 ; 0	0	20 ; 0	19 ; 0		+1		+13
22	FD (a)	3 ; 19	0	0 ; 5	0 ; 3		–5		–15
22	GDD Bud break*	7 ; 12	3	0 ; 4	0 ; 2		–3		–16
22	GDD Flowering*	2 ; 18	2	1 ; 15	0 ; 13		–7		–9
17	GDD Ripening*	0 ; 17	0	0 ; 14	0 ; 14		–19		–23
22	HI	22 ; 0	0	18 ; 0	17 ; 0	+273		+318	
22	STA10	20 ; 2	0	19 ; 0	17 ; 0	+203		+236	
22	STA10 Winkler	20 ; 2	0	19 ; 0	18 ; 0	+219		+252	
22	VGS0*	11 ; 6	5	4 ; 1	4 ; 1		+5		+15

Legend:

S – number of stations for which it was possible to calculate the trend,

(a) annual, (sp) spring, (s) summer, (au) autumn, (w) winter,

The asterisk means that Theil-Sen method was applied to calculate the slope (non-normal distribution),

n° – number of stations with positive and negative trend, respectively,

n – number of stations with slope = 0,

N°– number of stations with statistically significant coefficient ($p < 0.1$) with positive and negative trend, respectively,

NN° – number of stations with statistically significant coefficient ($p < 0.05$) with positive and negative trend, respectively,

m, m* – mean value of the regression coefficient for all the stations and mean value of the regression coefficient of the statistically significant stations (p < 0.10) (°C/50 year), respectively,
m1, m1* – mean value of the regression coefficient for all the stations and mean value of the regression coefficient of the statistically significant stations (p < 0.10) (days/50 year), respectively.
For the indices acronyms see Table 2.

Extreme summer temperature (TN90p and TX90p) indices show a positive trend too. In particular, the occurrences of warm nights show a greater increase than warm days (+17 days/50 years vs. +12 days/50 years). The number of days with minimum temperature lower than 0 °C (FD) highlights a slight decreasing trend.

Agroclimatological indices, in particular phenological phase indices, such as those referred to GDD, show an advanced tendency (*Fig. 2*). In particular, ripening phase shows a great advance tendency (–19 days/50 years).

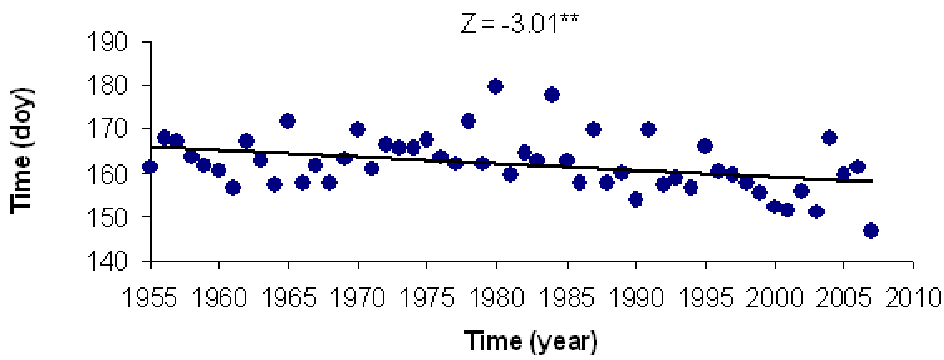

Fig. 2. Trend of the mean date of grapevine flowering for the 22 meteorological stations (1955–2007). ** = significance is greater than 99%; Z = standard normal distribution value; doy = day of the year.

The Huglin index (*Fig. 3*), according to the great rise of spring and summer temperatures, shows a generalized increasing trend in all over the region with a mean regional increase of 273 °C/50 years.

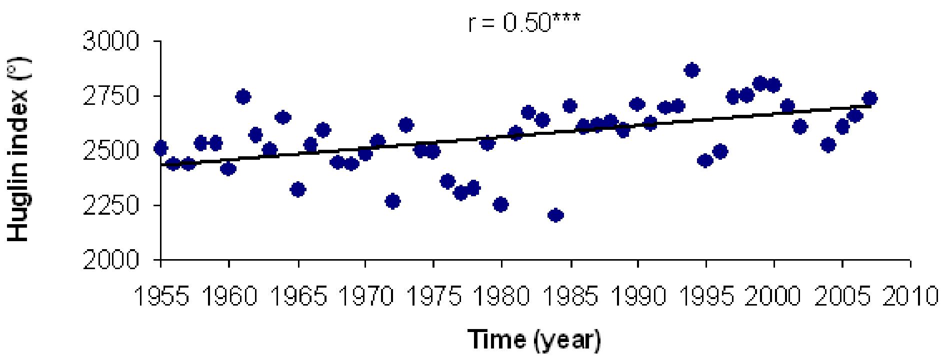

Fig. 3. Trend of the mean Huglin index for the 22 meteorological stations (1955–2007). *** = significance is greater than 99.9%; r = correlation coefficient.

Also STA10 (*Fig. 4*) and STA10 Winkler (*Fig. 5*) show positive trend (+203 °C/50 years and +219 °C/50 years, respectively). Vegetative growing season length with 0 °C threshold (VGS0) shows a slight positive trend (+5 days/50 year).

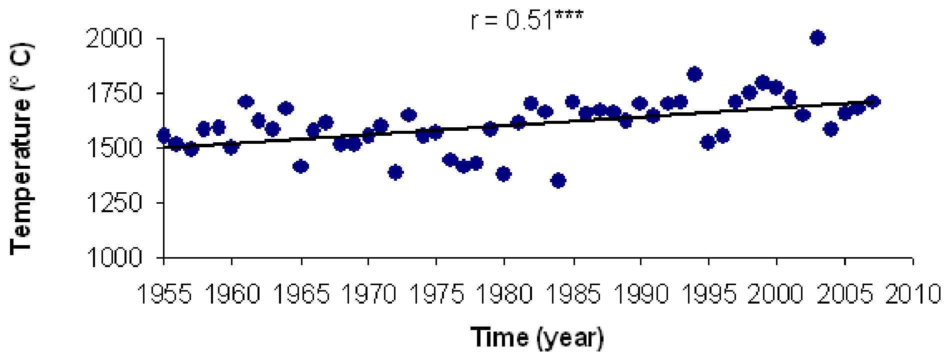

Fig. 4. Trend of the mean STA10 index for the 22 meteorological stations (1955–2007). *** = significance is greater than 99.9%; r = correlation coefficient.

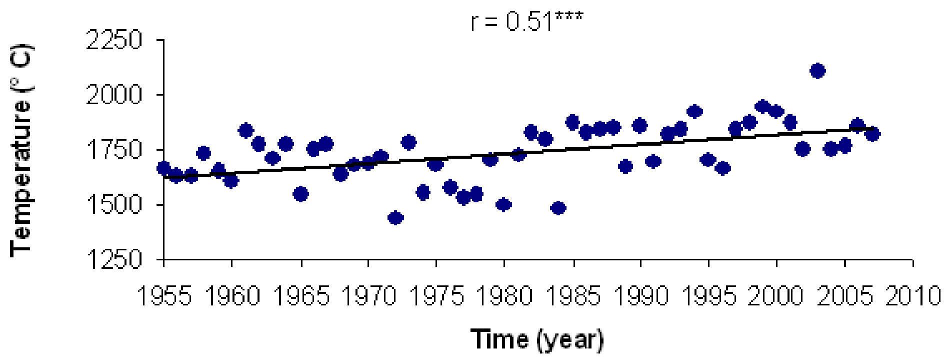

Fig. 5. Trend of the mean STA10 Winkler index for the 22 meteorological stations (1955–2007). *** = significance is greater than 99.9%; r = correlation coefficient.

4. Discussion and conclusions

The primary goal of this study was to assess Tuscany's annual and seasonal climatic and agroclimatic trend patterns, in order to more accurately represent local climate complexities and its potential impacts on grapevine. Moreover, the results of this study show a significant warming trend and a general advance in phenological phases confirming the global trend.

As grape quality is influenced by the temperatures in spring and summer, the observed temperature increase can produce physiological water stress and photosynthesis inefficiency (*Orlandini et al.*, 2005). Higher temperature summation lead to higher sugar accumulation in berry (*Gladstone*, 1992), less acidity and greater mean berry weight (*Fregoni*, 2002). Higher minimum temperatures speed up grape phenological phases and the advanced ripening affects the quality.

Huglin index shows general suitable conditions for grape varieties coming from southern region. Although frost day's trend is negative, late frosts damage risks are not decreased due to phenological general anticipations.

A more detailed research concerning the interannual variability by using standard deviation and moving average is need to understand the potential impacts on grapevine quality. Moreover, rainfall analysis and correlations with rising temperature may be useful to completely show the climate change effects on regional scale.

Acknowledgement—This study was performed with the support of Ente Cassa di Risparmio di Firenze.

References

Bartolini, G., Morabito, M., Crisci, A., Grifoni, D., Torrigiani, T., Petralli, M., Maracchi, G., Orlandini, S., 2008: Recent trends in Tuscany (Italy) summer temperature and indices of extremes. *Int. J. Climatol. 28*, 1751-1760, doi: 10.1002/joc.1673.

Bindi, M., Triossi, A., Moriondo, M., 2002: Mutamenti climatici e produzione vitivinicola europea. *L'Informatore Agrario 45*, 31-34.

Bindi, M., Fibbi, L., Gozzini, B., Orlandini, S., Miglietta, F., 1996: Modeling the impact of future climate scenarios on yield and variability of grapevine. *Climate Res. 7*, 213–224.

Brunetti, M., Maugeri, M., Monti, F., Nanni, T., 2006: Temperature and precipitation variability in Italy in the last two centuries from homogenised instrumental time series. *Int. J. Climatol. 26*, 345-381.

Fregoni, M., 2002: Adattamento della vite ai cambiamenti climatici futuri. *L'Informatore Agrario 45*, 29-30.

Gladstones, J., 1992: *Viticulture and Environment*. Winetitles, Adelaide.

IPCC, 2007: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by *S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor,* and *H.L. Miller*. Cambridge, UK and New York, NY, Cambridge University Press. 996p. (Available online from http://www.ippc.ch)

Jones, G.V., 2003: *Climate and Terroir: Impacts of Climate Variability and Change on Wine*. Geoscience. Pper 4 from the "Terroir, geology andwinea tribute to simon j. haynes" Session held at The Geological Society of American Annual Meeting, Seattle, Washington, November 2, 2003.

Jones, G.V., Hellman, E., 2003: *Site Assessment: in "Oregon Viticulture"* (ed.: *E. Hellman*). 5th Edition, Oregon State University Press, Corvallis, Oregon, 44–50.

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

Klein Tank, A.M.G., Können, G.P., 2003. Trend in indices of dayly temperature and precipitation extremes in Europe. *J. Climate 16*, 3665-3680.

Manton, M.J., Della-Marta, P.M., Haylock, M.R., Hennessy, K.J., Nicholls, N., Chambers, L.E., Collins, D.A., Daw, G., Finet, A., Gunawan, D., Inape, K., Isobe, H., Kestin, T.S., Lefale, P., Leyu, C.H., Lwin, T., Maitrepierre, L., Ouprasitwong, N., Page, C.M., Pahalad, J., Plummer, N., Salinger, M.J., Suppiah, R., Tran, V.L., Trewin, B., Tibig, I., Yee, D., 2001: Trends in extreme daily rainfall and temperature in southeast Asia and the south Pacific: 1961–1998. *Int. J. Climatol. 21*, 269–284, doi:10.1002/joc.610.

Maracchi, G., Sirotenko, O., Bindi, M., 2005: Impacts of present and future climate variability on agriculture and forestry in the temperate regions: Europe. *Climatic Change 70*, 117-135.

Mullins, M.G., Bouquet, A., Williams, L.E., 1992: *Biology of the Grapevine.* Cambridge University Press, Great Britain.

Nemani, R.R., White, M.A., Cayan, D.R., Jones, G.V., Running, S.W., Coughlan, J.C., Peterson, D., 2001: Asymmetric warming over coastal California and its impact on the premium wine industry. *Climate Res. 19*, 25-34.

Orlandini, S., Grifoni, D., Mancini, M., Barcaioli, G., Crisci, A., 2005: Analisi degli effetti della variabilità meteo-climatica sulla qualità del Brunello di Montalcino. *Rivista Italiana di Agrometeorologia 2*, 37-44.

Orlandini, S., 2004: La viticoltura di fronte ai cambiamenti climatici. Convegno IMaGONetafim "La vite e l'acqua", Sarteano, 26 Marzo 2004.

Peterson, T.C., Folland, C., Gruza, G., Hogg, W., Mokssit, A., Plummer, N., 2001: *Report of the Activities of the Working Group on Climate Change Detection and Related Rapporteurs. World Meteorological Organization Technical Document No 1071.* World Meteorological Organization, Geneva, Switzerland, 146.

Puglisi, A., Pastore, F., Orlandini, S., 2005: Analisi della variabilità climatica del territorio italiano. Implicazioni per la viticoltura. *Rivista Italiana di Agrometeorologia 9*, 70-71.

Schultz, H.R., 2000: Climate change and viticulture: An European perspective on climatology, carbon dioxide, and UV-B effects. *Australian Journal of Grape and Wine Research 6*, 2–12.

Sen, P.K., 1968: Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Association 63*, 1379-1389.

Theil, H., 1950: A rank-invariant method of linear and polynomial regression analysis, I, II, III. *Nederlandse Akademie van Wetenschappen 53*, 396-392, 512-525, 1397-1412.