

IPHEN: A MODEL FOR REAL TIME PRODUCTION OF GRAPEVINE PHENOLOGICAL MAPS

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Summary

IPHEN project is a co-operative effort for the production and broadcast of phenological maps for Italian area and involves several agro-meteorological services, university departments and research institutions. The project was based on a simulation model developed in order to produce fortnightly maps of phenological phases for two widespread grapevine varieties, the early one *Chardonnay*, and the late one *Cabernet sauvignon*.

The model was based on a simple and innovative method, founded on the summation of heating normal hours, instead of the classical growing degree days approach. Model operates on a highly detailed Digital Elevation Model, with pixel of 2 x 2 km. Thermal fields for maximum and minimum temperature were created applying specific geostatistical procedures to data acquired from the National Agrometeorological Network of CRA–UCEA. Calibration was carried out on bibliographic data coming from different regions of Italy. A standard routine to correct model results on the base of phenological data collected by a group of observers working on different parts of Italy was implemented. Final results were broadcasted on the Internet site www.ucea.it. Validation of model results, on the base of phenological data recorded in 2006, is presented and discussed. The choice of two phenologically extreme varieties was useful to describe spatial-temporal behavior of vine phenology in Italy. The robustness and the parsimony in terms of meteorological and phenological data requirements indicated that IPHEN approach (i) could evolve to an operational service referred to single terroir, entire countries or the whole European area and (ii) could be conveniently applied to other grapes varieties, different crops or wild species.

Key words: grapevines, phenology, real time maps,

Introduction

The knowledge at continental, national and local scale (*terroir*), of the grapevine phenological course, appears to be an important objective for a number of practical and scientific reasons. Current phenological course is an essential base of information for any previsional model for the estimation of potential yield and quality.

Weather course, in terms of limiting and stressing factors, as spring frost, rain shortage or excess, low or high temperature, may have very different effects, in relation to the phenological phase. On the other side, favourable weather conditions may have an effect on vine yield and grape quality potential, only if they match a specific and critical phenological phase, like flowering or the end of grape ripening. Moreover, different phenological periods have diverse critical and optimal meteorological conditions. If the year by year real time monitoring of the phenological course should represent a key information for yield analysis and forecast, the gathering of pluriennial data should be the base to develop capability and suitability map as a support for the guidance of European viticulture.

In spite of the large economical importance of viticulture in Europe, very few regional geographical studies on grapevine phenological timing have been achieved. Continental maps

for flowering, veraison and ripening dates of grapevines have been produced by an EU working group (Riou 1994), which main objective was to generate a capability map of Europe for the potential grape sugar accumulation. The phenological maps were obtained by processing data from 250 sites, collected for at least five years, for a total of 797 phenological occurrences. A more detailed series of phenological maps have been produced by an Italian research project, from data collected during a four year period, in 3582 vineyards all over the country (Calò et al. 1997). From the methodological point of view both works followed a multiple regression approach, by correlating phenological records and geographical and meteorological data of each site. A serious limit met by both projects was the availability of phenological data.

In the last three decades of the 20th century, many phenological networks were reduced in size or stopped because of a shortage of financial support. Although there has been a reduction in monitoring capacity, many countries still have active phenological monitoring networks and some of them are running since more than one century (Schwartz, 2003). These long-term data series have become an important reference for studies on the effects of climate variability and change on terrestrial ecosystems. However, there are several problems that limit the use of available phenological data:

1. the inadequate cooperation and communication between the existing regional and national phenological monitoring networks in Europe;
2. the lack of data access and integration, due to poorness of information on available datasets, on used definitions and techniques, on the quality of the data, and the only sporadic contact among involved persons;
3. the low efficient use and exchange of existing knowledge on tools and techniques already available for monitoring, data storage, data analyses, and the presentation of the results within and between the different scientific disciplines;
4. the scarce knowledge about the potential applications of phenological data.

In Europe, several common phenological activities have been carried out in the last ten years and a “phenological community” starts to become a concrete reality. One of the main achievement of this community is the convergence towards common standard and in particular the adoption of BBCH extended scale (Meier, 2001) as standard phenological scale. In Italy, the BBCH scale was suggested and adopted by “PHENAGRI” project (1997-2003) (Botarelli et al. 1999).

At European level, one of the phenological projects running at the present time is the COST action 725 “Establishing a European Phenological Data Platform for Climatological Applications”. This project has already chosen the reference period, the species and the phases to establish a common phenological database for climatological purposes.

In France the Phenoclim project, started in 2002, is collecting phenological data on fruit trees and grapevine with corresponding meteorological data: the aim is to improve the phenological models of these species, previously based only on temperature summations (Seguin 2003).

In order to Italian phenological activities, the main problem is the fragmentation (both in time and in space) of the initiatives and data, so every project at national level is very useful, especially if it goes on for several years.

A modern approach to phenology must utilize tools as the data spatialization techniques and modelling. Both these tools are essential also to get out of the main actual problem of agropenological networks: the high running costs of a network based on professional observers.

On these basis, IPHEN (Italian PHENological Network) project, for real time production of phenological maps at Italian national scale, has been proposed and developed starting from the 2006 growing season. Iphen project was promoted by a group of phenologists and crop

modelers, belonging to some universities, agrometeorological services, Cnr (National Research Council) and Cra-UCEA. The whole activity was referred to vine (*Vitis vinifera* L.) and black elder (*Sambucus nigra* L.); data carried out by observers in different areas of Italy were gathered and processed at Department of Crop Science of University of Milano. Internet broadcasting was carried out by Ucea Cra (www.ucea.it) and a subset of data is also available on <http://jolly.fi.ibimet.cnr.it/gilia/primavera/iphen.php>, the web site of Ibimet, the CNR phenological extension project.

Material and methods

Maps for vine, referred to the BBCH scale, were produced for the vegetative period (March – October 2006) and for two varieties (*Cabernet Sauvignon* – CS - and *Chardonnay* - CH). The whole work was referred to a Digital Terrain Model (DTM) of Italy with pixel of 2x2 km and geo-referenced with UTM 32T system (Fig. 1).

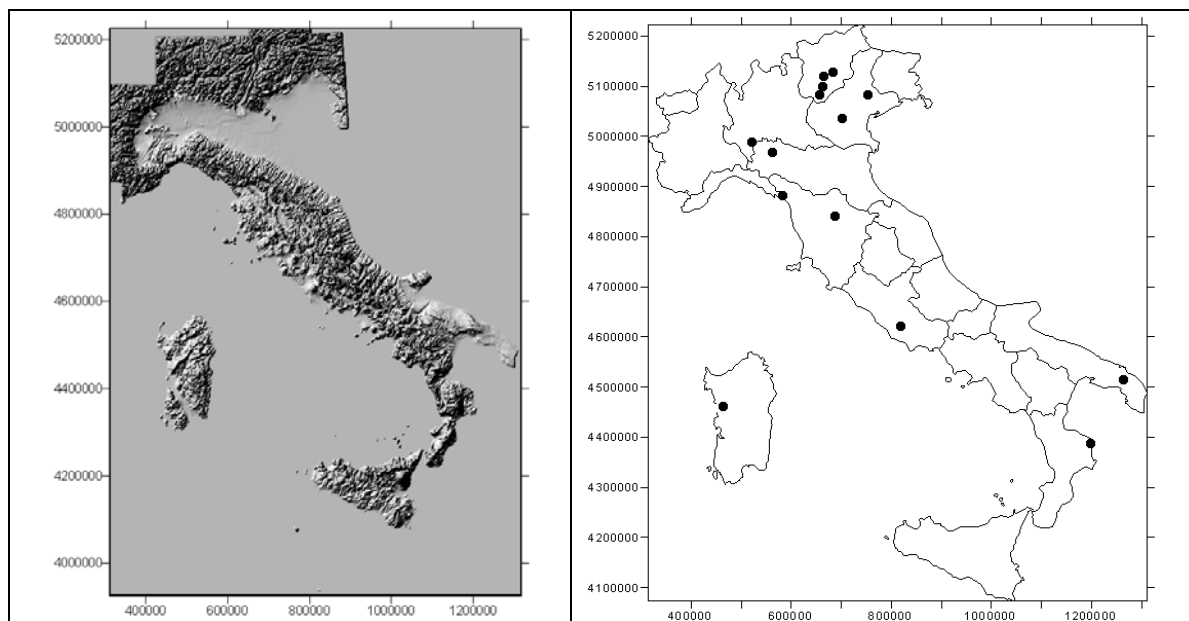


Figure 1 – Left: DTM with pixel of 2x2 km adopted for the reconstruction of thermal fields data. Right: locations of the phenological stations.

Coherently with the objective, the Extended BBCH phenological scale (Meier 2001) has been adopted. The grapevine BBCH phenological scale represents the conversion of the Eichhorn and Lorenz (1977) scheme into the general one of the BBCH phenological coding system. Differently from the still now frequently used Baggiolini (1952) scale, this methodology allows to constantly assign a phenological growth stage to the grapevines, all through the annual cycle, without any gaps of data.

To produce maps which could include most of the Italian variety assortment and, at the same time, could be comparable with other geographical proveniences, two widespread international cultivar have been selected: *Chardonnay*, a variety early both in bud break and grape ripening, and *Cabernet sauvignon*, which is late in bud break and medium-late in grape ripening.

The territorial approach to Normal Heat Hours (NHH) calculation

Phenological phases were estimated on the base of NHH, an analogous of the chill units adopted to evaluate thermal resources. The procedure of normalization was based on a generalized response function which varies from 0 to 1. The function adopted was a β

function (Wang and Engel, 1998) that gives 0 for temperatures outside minimum and maximum cardinals (respectively $T_{min} = 7\text{ }^{\circ}\text{C}$ and $T_{max} = 35\text{ }^{\circ}\text{C}$) and 1 for temperatures at optimum ($T_{opt} = 26\text{ }^{\circ}\text{C}$):

$$f_{vn}(T) = [2(T-T_{min})^{\alpha} (T_{opt}-T_{min})^{\alpha} (T - T_{min})^{2\alpha}] / (T_{opt}-T_{min})^{2\alpha}, \text{ for } T_{min} \leq T \leq T_{max} \quad (1)$$

and $f_{vn}(T) = 0$ for $T < T_{min}$ or $T > T_{max}$
 where $\alpha = \ln[2/\ln((T_{max}-T_{min})/(T_{opt}-T_{min}))]$

Normal values of NHH corresponding to some phenological stages of *Chardonnay* and *Cabernet Sauvignon* for some Italian stations are presented in table 1.

The mean hourly temperatures of each ten-days of 2006 were obtained by means of the following algorithm:

- The ten-day averages of maximum and minimum temperatures (T_x , T_n) were calculated for about 90 meteorological stations of the Italian area belonging to the networks of UCEA – CRA and Air Force Meteorological service
- decadal temperatures T_x and T_n for each unknown point of the entire Italian grid of 2 x 2 km were produced by means of the method of inverse square of distance weighted interpolation, applied to the whole set of known data points, previously homogenized for height and aspect to the unknown point
- Once obtained the mean ten-day fields of T_x , T_n for the whole Italian area, the mean hourly data for each grid point were obtained applying the Parton and Logan (1981) algorithm.

NHH method applied to these hourly data produced a field of NHH for the given ten-days. The summation of ten-day fields gives the NHH cumulated from the beginning of the year.

Table 1 – NHH normal values for some different phenological phases calculated for some Italian locations.

Cultivar	Phenological phase					
	Location	Latitude (°)	Sprouting (BBCH 8)	Flowering (BBCH 65)	Veraison (BBCH 81)	Ripening (BBCH 89)
Chardonnay	Cagliari	39	336	894	2053	2899
	Sigonella	37	335	885	1868	2349
	Firenze	44	258	890	1906	2549
	Ronchi	45	175	810	1906	2506
	Bergamo	45	121	764	1829	2521
Cabernet Sauvignon	Cagliari	39	401	1005	2068	2966
	Sigonella	37	400	1004	2067	2965
	Firenze	44	323	927	1990	2888
	Ronchi	45	240	844	1907	2805
	Bergamo	45	186	790	1853	2751

The model of correlation between NHH and BBCH phase

Logarithmic equations that describe the correlation between NHH and phenological data for *Cabernet Sauvignon* and *Chardonnay* referred to 1987-1990 period (Calò et al., 1997) are listed in table 2.

The correlation between latitude and coefficients a, c of the logarithmic equations in table 2 can be represented with the linear functions in table 3:

Table 2 – Logarithmic regressions and relative correlation coefficients between $y=BBCH$ and $x=NHH$ for *Cabernet Sauvignon* and *Chardonnay*

Cultivar	Location	Latitude	Equation $y=a * \ln(x)+c$	r^2
Chardonnay	Cagliari	39	$y = 36.738 * \ln(x) - 198.36$	0.9319
	Sigonella	37	$y = 40.611 * \ln(x) - 222.45$	0.9517
	Firenze	44	$y = 35.207 * \ln(x) - 183.41$	0.9702
	Ronchi	45	$y = 30.216 * \ln(x) - 145.03$	0.9803
	Bergamo	45	$y = 26.678 * \ln(x) - 117.84$	0.9890
Cabernet Sauvignon	Cagliari	39	$y = 40.013 * \ln(x) - 224.70$	0.9348
	Sigonella	37	$y = 39.973 * \ln(x) - 224.37$	0.9349
	Firenze	44	$y = 36.750 * \ln(x) - 198.09$	0.9460
	Ronchi	45	$y = 32.943 * \ln(x) - 167.47$	0.9596
	Bergamo	45	$y = 30.174 * \ln(x) - 145.50$	0.9695

Table 3 – Linear regression and relative correlation coefficients between latitude and coefficients of equations of table 2

Cultivar	Equation	r^2
Chardonnay	$a = -1.2888 * \text{lat} + 88.020$	0.7717
	$c = 9.8554 * \text{lat} - 587.340$	0.7747
Cabernet Sauvignon	$a = -1.0187 * \text{lat} + 78.757$	0.7675
	$c = 8.2296 * \text{lat} - 537.670$	0.7712

These algorithms can be synthetized in a final model for phenology of the two selected varieties, represented by the following equations:

for *Cabernet Sauvignon*:

$$BBCH = (-1.0187 * \text{lat} + 78.757) * \ln(NHH) + 8.2296 * \text{lat} - 537.67 \quad (2)$$

For *Chardonnay*:

$$BBCH = (-1.2888 * \text{lat} + 88.02) * \ln(NHH) + 9.8554 * \text{lat} - 587.34 \quad (3)$$

The production of first guess and final maps

Applying equations (2) and (3) to NHH data cumulated from the beginning of the year, a First Guess Field (FGF) of BBCH phenological phases for CS and CH was produced. A match of FGF data with data coming from observers was used to produce an error field (EF) spatialised to the intere territory by means of an inverse square of distance weighted interpolation. EF was adopted for the correction of FGF. In this way a Final Field (FF) was obtained and used to produce maps with a standard Gis program.

Results

Annual weather conditions of 2006

Thermal-pluviometric behavior was analysed considering 2006 meteorological data and 1971-2000 climatic normals for the stations of Verzuolo (Piedmont region - Northern Italy), Arezzo (Tuscany - Central Italy) and Sibari (Calabria - Southern Italy).

The analysis show that 2006 year presents two different thermal phases, with a negative anomaly in the first part of the year followed by a positive thermal anomaly. The change of phase was earlier in the North (April) medium in the Centre (June) and later in the South (end of July). Precipitation was below the normal in the North, particularly for the period from May to the beginning of September. In the Centre was also present a small negative anomaly and in the South was present a small but persistent positive anomaly.

Phenological timings

Data were collected from 9 phenological stations for *Cabernet sauvignon* and 10 for *Chardonnay*, located in northern, central and southern Italy (Fig. 1).

As expected, *Chardonnay* was earlier than *Cabernet Sauvignon* (Fig. 2C): on average it completed bud-break (BBCH code > 10) within April 10th (DOY 100), flowering (BBCH code > 69) within June 20th (DOY 171) and grape ripening (BBCH code 90) within September 20th (DOY 263). On the contrary, phenological stages related to berry growth before veraison, did not show difference between the two varieties. Comparing the differences between the earliest and the latest phenological station (Fig. 2A-B), in both varieties the highest differences in the phenophase timing were recorded in the middle part of the growing season and in particular for the flowering. In both the cultivars the range for the stage “end of flowering” could be estimated in 40 days, while it was around 30 days for the bud-break as well as for the grape ripening phase.

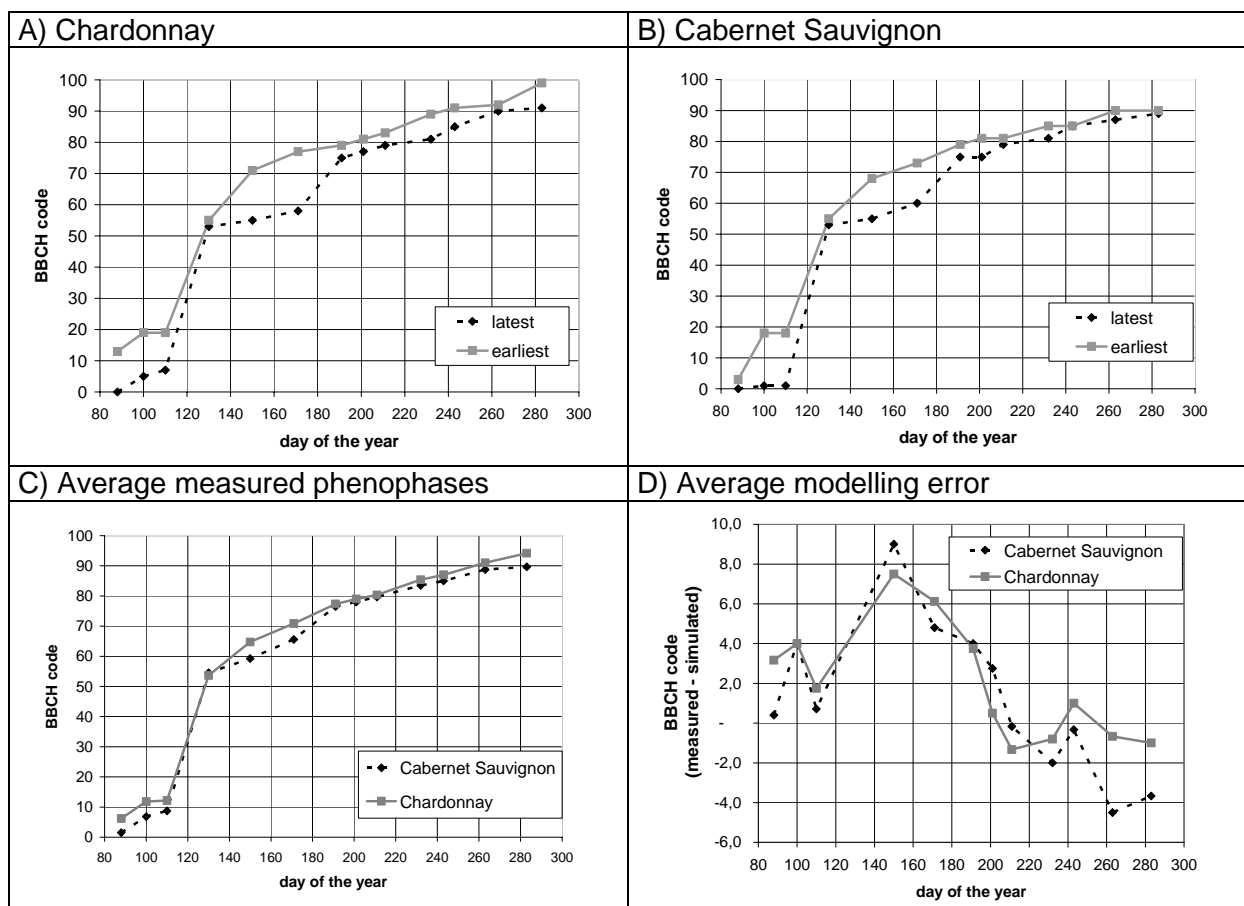


Figure 2 – Above. A-B) Comparisons between the earliest and the latest phenological records in the two tested cultivars. Below. C) Cultivar comparisons between the average measured phenological phases. D) Trends of the absolute errors (averaged for all stations) in the two cultivars during the growing season.

Evaluation of the error in the simulation of phenophases

The average absolute error in the estimation of the phenophases, in terms of measured BBCH codes minus simulated ones, showed (Fig. 2B) positive values with an increasing trend during the first two months of the growing season; substantial decline with around zero values at the end of July (DOY 200-210); after this phase, the error stayed very close to zero until the end of the season in *Chardonnay*, whilst in *Cabernet Sauvignon* the error remained low until the end of August (DOY 243) but attained slightly more negative values in the end of the season.

From the practical point of view this means that, in *Chardonnay*, when the model simulated “mid-flowering”, the records indicated the “end of flowering”; while in *Cabernet Sauvignon*, when the model simulated the “beginning of flowering” the records indicated the “end of flowering”. Moreover if in *Chardonnay* the grape ripening was well simulated, in *Cabernet Sauvignon* the model simulated grape ripening 20 days in advance.

Geographical ranges in grapevine phenology

Maps of BBCH phenological phases for *Cabernet Sauvignon* and *Chardonnay* were produced for the vegetative period (March – October 2006) with a time step of about 15 days and are available on the web site www.ucea.it. Examples referred to May 10th are presented in figure 4. The main phenological effect of the specific annual meteorological conditions was the anomalous precocity in the North, driven by high thermal resources and low water resources with an inversion of normal latitudinal gradient of precocity: phenological maps of 2006 (www.ucea.it) show that the North was earlier than the South until the end of July. Phenological maps show some geographic and climatic effects that are emphasised by the adoption of two “extreme” varieties. For example the picture of May 10th show that *Chardonnay* completed the bud-break (red in the map) in the main part of the cultural area, whilst gradient driven by latitude and distance from sea is evident in *Cabernet Sauvignon* (note in the map that bud-break in Northern Italy is complete in the East due to the effect of the Adriatic sea).

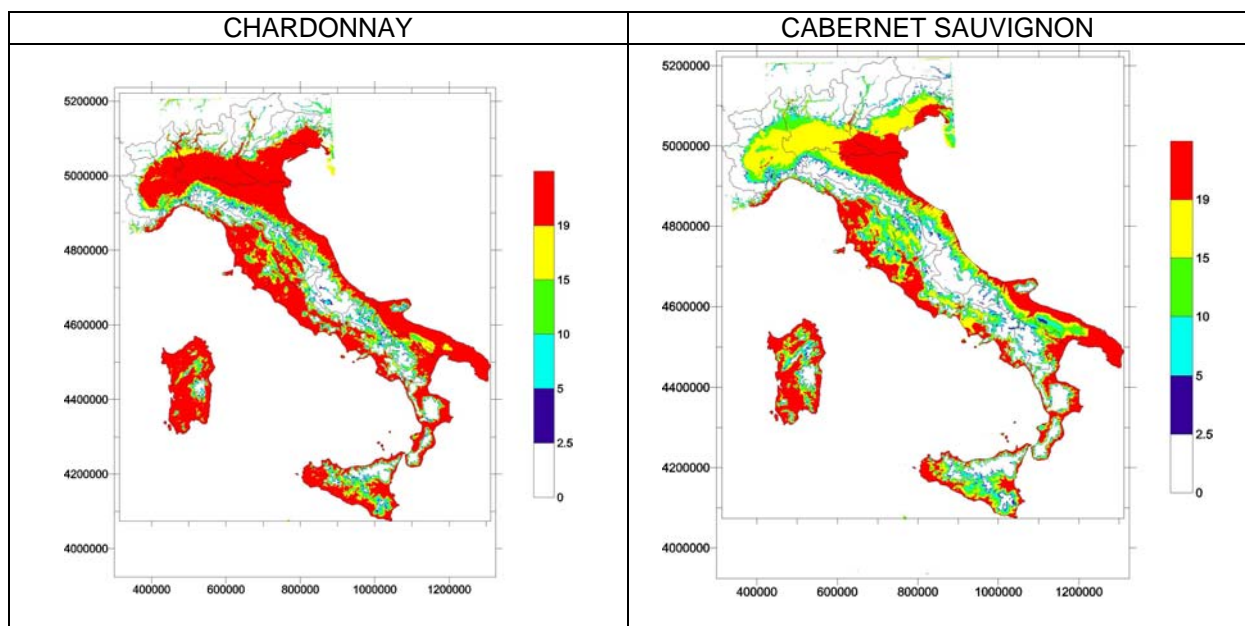


Figure 4 – Phenological maps developed by IPHEN project on May 10th

Discussion and Conclusions

The main limitation in order to achieve robust conclusions from the data obtained in the 2006 prototypal phase of IPHEN project are the shortness of one year of data and the quite irregular spatial distribution of observations. Another possible limitation is represented by the description of micrometeorological features of the Italian territory. A typical example of this kind of problem is represented by thermal inversions during winter (thermal belt effect). However some original evaluations can be done for the whole Italian territory and in particular: (i) the choice of two phenologically extreme varieties is substantially correct to describe spatial-temporal behavior of vine phenology in Italy; (ii) the substantial decrease of

the error with the progression of the season shown by the two varieties and in particular by *Chardonnay*. Furthermore phenological observations are strategic for this kind of project because (i) are useful in order to correct the errors of model during the process of production of maps and (ii) represent a dataset of field measurement useful for the re-calibration of the model that can be carried out at the end of the phenological season. On the base of the results obtained in the first year, it is possible to affirm that the approach adopted for IPHEN project is sufficiently robust and parsimonious in terms of meteorological and phenological data requirements. The consequence is that IPHEN approach (i) could evolve to an operational service referred to single terroirs, entire countries or the whole European area and (ii) could be conveniently applied to other varieties of grapevine or other crops or wild species. This latter possibility was already explored by IPHEN project with a specific test of production of maps for black elder (*Sambucus nigra* L.) carried out in 2006 parallely to the experiment on grapevine.

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Bibliographical references

- Baggiolini M. 1952 Les stades rèperes dans le développement annuelle de la vigne et leur utilisation pratique. Rev. Rom. Agric. Vitic. Arboric., 8:4-6.
- Botarelli L. et al. (editor) 1999 La scala BBCH. In: Aspetti generali delle osservazioni agrofologiche. Ministero delle politiche agricole e forestali, Roma: 87-93.
- Calò A. et al. 1997 La fenologia della vite in Italia in rapporto alle condizioni ambientali. In: Ministero per le risorse agricole e alimentari e forestali, Il determinismo climatico sulla fenologia della vite e la maturazione dell'uva in Italia. Arti grafiche Conegliano: 3-71.
- Eichhorn K.W. and Lorenz Lorenz D.H. 1977 Phäenologische Entwicklungsstadiender Rebe. Nachrichtembl. Deut.Pfanzenschutzd. (Brawnschweig), 29:119-120.
- Meier U. 2001 Growth stages of mono-and dicotyledonous plants. BBCH Monograph. 2. Edition. Federal Biological Research Centre for Agriculture and Forestry. 158 pp.
- Parton W.J. and Logan J.A. 1981 A model for diurnal variation in soil and air temperature, Agric. Meteorol., 23: 205-216.
- Riou C. (editor) 1994 Le déterminisme climatique de la maturation du raisin: application au zonage de la teneur en sucre dans l Communauté Européenne. EUR Publication N° 15863 FR/EN of the Office for Official Publications of the E.C.; Series Agriculture. Luxembourg, 322 pp + 4 color maps
- Schwartz M.D. (editor) 2003 Phenology, an integrative environmental science. Kluwer Academic Publishers, Boston , Dordrecht , London, 564 pp.
- Seguin B. 2003 The Phenoclim database for fruit trees and vine in France. In: Proceedings of the international conference Challenging Times, Wageningen: 75-78
- Wang E. and Engel T. 1998 Simulation of phenological development of wheat crops, Agricultural systems, vol. 58, 1: 1-24.