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Calibration and validation of grapevine budburst models using growth-room experiments as data source

Gianni Fila[a,e,*], Bruno Di Lena[b,d], Massimo Gardiman[a], Paolo Storchi[c], Diego Tomasi[a], Oriana Silvestroni[d], Andrea Pitacco[e]

[a] Centro di Ricerca per la Viticoltura (CRA-VIT), I-31015, Conegliano (TV), Italy
[b] Regione Abruzzo, ARSSA, Centro Agrometeorologico Regionale, I-66020, Scerni (CH), Italy
[c] Unità di Ricerca per la Viticoltura (CRA-VIC), I-52100, Arezzo, Italy
[d] Università Politecnica delle Marche, Dipartimento di Scienze Ambientali e Produzioni Vegetali, I-60131, Ancona, Italy
[e] Università di Padova, Dipartimento di Agronomia Animali Alimenti Risorse Naturali e Ambiente - DAFNAE, Agripolis, I-35020, Legnaro (PD), Italy

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ABSTRACT

Robust calibration of phenological models requires long term field observations, which are not always available or sufficiently widespread. This has motivated the evaluation of short-term experiments using cuttings under semi-controlled conditions as an alternative data source. Single-node cuttings from two grapevine cultivars were exposed to variable chilling durations and allowed to sprout in a growth room. The observed budburst dates and temperature series were used to calibrate two budburst models, which were validated against a 39-year field observation dataset by means of a fuzzy-logic based integrated index (FI). Satisfying validation scores were obtained, ranging from 0.262 to 0.411 on a 0-1 scale (best-worst response).

The experiment was then inverted, using field data for calibration and cuttings for validation, and FI scores ranging between 0.352 and 0.495 were obtained. On this occasion however, the models were not able to estimate budburst occurring after short chilling exposures, where they returned either high overestimations or failed completely. This was due to the narrow winter length variability in the field dataset, which made the optimization algorithm converge towards unrealistically high chilling requirements and artifactual descriptions of the temperature effects on dormancy. Cutting-based calibration on the other hand produced parameterizations that were more consistent with available experimental knowledge.

Despite this difference between them, the two approaches proved to be equivalent under the climatic conditions present, but not when tested on projected scenarios of climate change over the period 1990–2090, where cutting-calibrated models, which are more sensitive to decreasing winter length, predicted higher variations of the budburst dates.

1. Introduction

Models of grapevine phenology are becoming popular tools for assessing the impact of climate change on viticulture (Webb et al., 2007; Kwon et al., 2008; Caffarra and Eccel, 2011; Duchêne et al., 2010) and for supporting GIS-assisted zoning studies to identify the most suitable areas for specific cultivars (Bois et al., 2008; Scaglione et al., 2008). Given the growing interest in these kinds of applications, which are characterized by high degrees of extrapolation across many environmental conditions on both spatial and time scales, model robustness represents a crucial issue (Caffarra and Eccel, 2010).

The more up-to-date phenology models of perennial plants combine the description of dormancy dynamics in overwintering buds with a heat-sensitive development phase, often termed “forcing phase”, leading to budburst (e.g. Richardson et al., 1974; Cannell and Smith, 1983; Cesaraccio et al., 2004; Chuine, 2000; de Cortázar-Atauri et al., 2009). They are considered an evolution from the more traditional ones, based only on the accumulation of heat units from a fixed date, which are collectively referred to as “Thermal Time models” (e.g. Cannell and Smith, 1983; Linkosalo et al., 2008) or “Spring Warming models” (e.g. Hunter and Lechowicz, 1992; Parker et al., 2011). These latter models differ in how heat units are calculated: Growing Degree Day (GDD, Winkler et al., 1974; Bonhomme, 2000), or variously defined functions of daily temperature (e.g. Chuine et al., 1999b; Parker et al., 2011).

Compared to Thermal Time models, those accounting both for chilling and forcing adapt more easily to environment and genotype variability, but due to increased complexity they require

* Corresponding author at: Centro di Ricerca per la Viticoltura (CRA-VIT), I-31015 Conegliano (TV), Italy. Tel.: +39 0438 456778; fax: +39 0438 450773.
E-mail address: gianni.fila@entecra.it (G. Fila).

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considerable amounts of experimental data for parameterization and validation to reach adequate robustness and to avoid overfitting.

It is precisely this that represents one of the biggest limitations in phenology research. Since development stages can be observed in the field once a year only, it takes decades to assemble a sufficiently large dataset. But even when long historical data series are available, they may be biased by heterogeneities in plant material, or in the criteria for identifying the phenological stage, not to mention eventual gaps in meteorological data.

In this work we have evaluated the possibility of using repeated growth room experiments with grapevine cuttings to build a dataset for the calibration and validation of budburst models. Evaluated against field observations this approach presents a number of advantages. First of all, vine cuttings require small areas and can be induced to budburst in only a few weeks, therefore many experiments can be concentrated over a relatively short period of time whilst ensuring a high variability of conditions. Furthermore, budburst dates and temperatures can be recorded with high homogeneity and accuracy. In a short time it should therefore be possible to build a phenological dataset sufficiently large to alleviate the lack of field observations or to integrate them if they are scarce. Another advantage is the possibility of observing plant behaviour under a wider range of climatic conditions, which can be varied at will. This allows for minimization of local specificity which translates into a higher level of generalization and greater robustness, both desirable features for applications involving spatial estimates and/or projections into the future.

Many studies in the past have already used cuttings under controlled conditions for investigating the effect of temperature on grapevine budburst (Pouget, 1967; Weaver et al., 1975; Calò et al., 1976; Dokoozlian, 1999), but none of the ensuing information has been incorporated into a mathematical model to gain a comprehensive understanding of experimental results and to facilitate their practical exploitation.

Our objectives were (i) to assess whether budburst data derived from growth room experiments can effectively replace long term field datasets used for model calibration, (ii) to analyse the consistency of the obtained parameterization, and (iii) to evaluate its application to long-term predictions related to climate change.

2. Materials and methods

2.1. Cutting sampling and handling

Dormant one-bud cuttings from the cultivars ‘Montepulciano’ and ‘Sangiovese’ were repeatedly excised from a vineyard located at Scerni, in the Abruzzo region (Central Italy, 42.10N, 14.57E) during three consecutive Autumn/Winter seasons between 2007 and 2010. Vines were grafted on Kober 5BB rootstock and trained to a spur-pruned cordon system with 3 m × 1.5 m plant spacing. Samplings started when at least seven days with daily mean temperatures below 10 °C were recorded. This condition occurred in mid October, 2007 and 2009, and at the end of November in 2008. In the first two seasons ten and nine samples were taken, respectively, up until the month of March, whilst only two samplings in January and February were executed in the third season (Table 1).

Each sample ($n = 90$) was put into a growth room under semi-controlled conditions, where temperature maintained a diurnal variation of 8.0 ± 2.5 °C above that outside, so that during the experimental campaign maximum and minimum temperature increased from 10 to 25 °C and from 6 to 18 °C, respectively. In order to increase chilling duration variability, in some of the treatments part of the samples were kept in a separate room at 2–3 °C for 10–35 days prior to placing them under growth conditions. Budburst was recorded when 50% of the buds reached stage 09 of the BBCH scale for grape (Lorenz et al., 1994).

Table 1
Dates of grapevine cutting samplings. In brackets, the duration of the cold treatment at 2–3 °C prior to the forcing treatment in growth room.

	2007/2008	2008/2009	2009/2010
1	22 November (0)	11 November (13)	5 January (0)
2	3 December (0)	22 December (0)	5 January (10)
3	18 December (0)	2 February (0)	2 February (0)
4	3 January (0)	2 February (16)	
5	21 January (0)	2 February (31)	
6	5 February (0)	24 February (0)	
7	5 February (14)	24 February (35)	
8	5 February (28)	5 March (0)	
9	19 February (0)	5 March (26)	
10	4 March (0)		

2.2. Budburst field data

Historical budburst records were provided by the ampelographic collections from the Research Centre for Viticulture located in Susegana (North-Eastern Italy, 45.85N, 12.26E) and from the Research Unit for Viticulture located in Arezzo (Central Italy, 43.29N, 11.90E), both being structures of the Agriculture Research Council (CRA). The collections have the same planting scheme with a Sylvoz training system and a 3 m × 1.5 m plant spacing. Both cultivars were grafted on SO4 rootstock.

Data from Susegana were collected from 1985 to 2010, with two missing years (2003 and 2007), whereas data from Arezzo were collected from 1996 to 2010. A total of 39 annual records were therefore available for each cultivar.

Both vineyards were equipped with on-site automatic meteorological stations, which recorded daily maximum and minimum temperatures.

2.3. Models

The ‘Unified’ and ‘Unichill’ models (Table 2) developed by Chuine (2000) were calibrated with the growth room results and validated with the field data. Both models assume that dormancy is a two-stage process, starting with a “rest” period which ends when daily accumulation of chilling units starting from September 1st reaches a critical sum (C_{crit}). At this point the second stage begins called “quiescence”, in which heat units (or ‘forcing units’) are accumulated until budburst occurs as soon as another critical sum (F_{crit}) is reached. Daily values of chilling and forcing units are calculated using temperature dependent functions. In the Unified model F_{crit} decreases during a sensitive period (T_c) according to an exponential decrease function of the total accumulated chilling, whilst in Unichill it is a fixed empirically determined parameter.

Table 2
Description of the ‘Unified’ and ‘Unichill’ models (further details in the text).

Eq. (1) Daily chilling unit (c.u.)	$\text{c.u.} = \frac{1}{1+e^{a_c\cdot(T_{avg}-c_c)^2+b_c\cdot(T_{avg}-c_c)}}$
Eq. (2) Daily forcing unit (f.u.)	$\text{f.u.} = \frac{1}{1+e^{b_f\cdot(T_{avg}-c_f)}}$
Eq. (3) Critical f.u. sum (Unified model)	$F_{crit} = W \cdot e^{(-k\cdot Sc)}$

- a_c, b_c, c_c – empirical parameters of the c.u. vs. temperature function
- b_f, c_f – empirical parameters of the f.u. vs. temperature function
- Dormancy breaks when c.u. summation reaches a critical value (C_{crit})
- Budburst occurs when f.u. accumulation reaches a second critical value (F_{crit})
- W, k – empirical parameters of the F_{crit} adjusting function in the Unified model
- Tc – length of the period (days) where Eq. (3) applies
- T_{avg} – daily mean temperature
- Sc – totally accumulated c.u. within the Tc period