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BIOCLIMATIC REQUIREMENTS FOR OLIVE FLOWERING IN TWO MEDITERRANEAN REGIONS LOCATED AT THE SAME LATITUDE (ANDALUCIA, SPAIN, AND SICILY, ITALY)

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Abstract: The Mediterranean Region is the major area devoted to olive tree crop, and therefore a study of olive flowering is of great interest for the European Community. On the other hand, olive pollen is one of the main causes of pollen allergy in the Mediterranean area. Olive flowering is affected by climatic factors such as temperature and photoperiod, which vary geographically in latitude and altitude. Temperature has been used to study those processes that lead to flowering in the olive tree. The aim of the present paper is firstly the comparison of the flowering full bloom dates in two Mediterranean areas, Sicily (Italy) and Cordoba (Spain), located in the same latitudinal band (37-38º N) and to calculate the heat requirement until flowering by determination of different threshold temperatures and methods of heat accumulation. A delay of the full flowering dates in the Spanish compared with the Italian olive groves was observed. The most suitable threshold temperatures were carried out in a 7°-15°C range by considering the heat accumulation start on 1 January in each olive grove. In particular, some causes were indicated as responsible for the different threshold temperatures recorded in the 2 study areas: First, the different climatic conditions (continental and insular climate) secondly the different cultivars present in the olive groves.

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INTRODUCTION

The Mediterranean Region is the main area in the world devoted to the olive tree crop (*Olea europaea* L.), where it is one of the most important agricultural activities [7]. This crop has an increasing economic interest for the European Community, and overall for its two most important olive oil producers - Spain and Italy - for the management of agricultural policies (stock management, price formation, etc.).

On the other hand, the spread of this crop is leading to negative consequences for environmental health. Olive pollen is one of the main causes of pollen allergy in the Mediterranean area [8] and is the principal cause of allergy in several parts of Andalusia (Spain) [11]. Moreover, this is a problem which is recently increasing, overall in rural areas due to the European Community policies that favour the cultivation of olives in areas traditionally devoted to different crops.

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Knowledge and forecasting of the flowering behaviour provides useful data for both forecasting olive fruit yields [15, 17] and useful information to manage and prevent allergic symptoms [10].

Flower phenology has been widely used by several authors to study the flowering in plant species of economic interest. This discipline focuses on the timing of flower development as a recurring biological event, the causes of the timing of flowering with respect to biotic and abiotic forces, and the inter-relationship between phases of the same species [21]. In phenology, the olive flowering period may be described by several developing phases or "phenophases" reflecting the percentage of opened flowers with respect to the total tree canopy [22]. Likewise, several authors have recently affirmed that the pollen emission period indicates the main phase of the olive reproductive cycle [4, 16, 19]. In fact, the correspondence between the olive pollen season and the main flowering phenological phase has been fully demonstrated by several authors [12, 13].

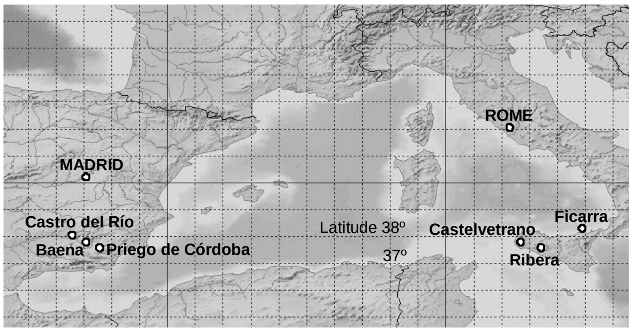
Olive flower phenology is characterised by an annual cycle, including bud formation during the previous summer, dormancy during the cold period, budburst in late winter, and flower structure development from budburst to flowering in spring. Of all the factors affecting plant development, temperature and photoperiod exert the strongest effect on vegetation development and especially on flowering [5]. The variation in temperature and photoperiod due to altitude and latitude makes early spring generative phenophases differ geographically [21, 30]. Pronounced differences in olive flowering dates have been reported in the Mediterranean area, both between different countries [12] and at the regional level [17]. Temperature has been widely accepted as the most important factor affecting processes that lead to flowering in olive trees. A vernalization or chilling period is required in the period prior to flowering [20, 27]. Afterwards, the determination of heat requirements in the first developing phases of plants has been expressed as temperature accumulation by means of parameters such as Heat Units, which are usually expressed as Growing Degree Days (GDD). Their determination is useful for achieving a better understanding of the flowering season development in several plant species, and for forecasting when flowering will occur. The determination of the most suitable threshold temperature in different geographical locations by means of heat accumulation has been described by several authors [17, 18, 28, 29].

The aim of the present study is to compare the full flowering dates and the corresponding heat requirements in olive groves from Spain and Italy from 1999 to 2004. In particular, two aims were considered: 1) to verify the "similarities/differences" among flowering dates in olive groves located in remote areas at the same latitude; 2) to investigate in each study area the relationships between heat amount (GDD) from the dormancy period and the full bloom dates, by the determination of different threshold temperatures and different methods of heat accumulation.

MATERIALS AND METHODS

Study areas. Two different areas were studied over six years (1999–2004): the region of Sicily, Italy; and the province of Cordoba in Andalusia, Spain. Data from three olive groves were used in each area. These sampling sites were chosen according to their location within a close latitudinal band between 37.43º N in the southern part (Priego de Córdoba, Spain) and 38.06º N in the northern part (Ficarra, Italy). Both study areas are characterised by a Mediterranean climate. Due to this fact, similar average temperatures are registered during the first semester in both areas - 13.8ºC in Sicily and 12.8ºC in the Córdoba province. The slight difference of 1ºC between both study areas could be related to the higher altitude and level of continentality of the Spanish compared to the Italian area. The main features of each olive grove are shown in Figure 1. Taking into account the different cultivars in each olive grove, the Italian olive groves were represented by "Biancolilla" in Ribera (Agrigento), "Nocellara" in Castelvetrano (Trapani), and "Minuta" in Ficarra (Messina). In the Spanish olive groves, the "Picual" cultivar was the most representative in Castro del Río, whereas "Picudo" and "Hojiblanca" were the two main cultivars in Baena and Priego de Córdoba (Spain), respectively.

Determination of main flowering dates. Phenological observations in the field were performed in order to determine the main flowering dates of the olive crops. The olive tree phenophases proposed by Maillard (1975)



Province (Country)	Olive grove location	Coordinates	Altitude (m. a.s.l.)	sea-distance (km)	Cultivar in the grove
Agrigento (Italy)	Ribera	13.27ºE 37.5ºN	400	6	Biancolilla
Trapani (Italy)	Castelvetrano	12.78ºE 37.68ºN	120	5.5	Nocellara
Messina (Italy)	Ficarra	14.75ºE 38.06ºN	400	5	Minuta
Córdoba (Spain)	Castro del Río	4.48ºW 37.68ºN	300	108	Picual
Córdoba (Spain)	Baena	4.32ºW 37.62ºN	500	97	Picudo
Córdoba (Spain)	Priego de Córdoba	4.18ºW 37.43ºN	800	79	Hojiblanca

Figure 1. Main features of the six olive groves: the Provinces and locations, coordinates and altitudes (m. a.s.l.), cultivars present in the groves.

were applied to the phenological observations. According to this author, the phenological observations were performed weekly on 10 olive trees from each olive grove during the whole of flower development in order to determine the exact flowering start date from direct observations. In this connection, an average of the phenological stage for each olive grove and date was determined, and a trend line representing the phenological evolution in time for each olive grove was plotted. The phenophase in which most of the flowers over the tree canopy are open is defined as full bloom so the timing corresponding to this phenophase start was considered as the main flowering date.

Analysis of the GDD calculation methods and threshold temperatures determination. Up to seven different GDD calculation methods were utilized to determine the daily GDD in each area. Yearly GDD amounts were carried out, considering 1 January as the start date, and the days of maximum flowering as the final dates.

Method 1: Single Triangle Method [33] draws a straight line between a day's minimum and maximum temperature, assumes the next day's minimum temperature is the same, and draws another line to that point, forming two sides of a triangle. This method assumes the temperature curve is symmetrical around the maximum temperature.

Method 2: Single Sine Method [26, 33] uses a day's minimum and maximum temperatures to produce a sine curve over a 24-hour period, and then estimates degree-days.

Method 3: Allen Method [2] was obtained from the modified sine wave method. The model provides for the reconstruction of the daily thermal cycle by a sine curve on the basis of the daily maximum and minimum temperatures.

Method 4: Wit Method was initially presented by Wit *el al.* [32] and uses a cosine function for the period from the time of minimum temperature to the time of maximum temperature, and another cosine function from the time of the maximum temperature to the time of minimum temperature the next day.

Method 5: Wilkerson Method [31] assumes a change from night to day temperature at sunrise +2 h and the night temperatures are linear with time. In addition to the current day's TMAX and TMIN, the method requires the TMAX and TMIN of the previous day and the TMIN of the following day.

Method 6: Parton-Logan Method [25] divides the day into two segments and utilizes a truncated sine wave in daylight and an exponential decrease in temperature at night.

Method 7: "Cesaraccio" Method [6] uses two sine wave functions in daylight and a square-root decrease in temperature at night. The sunrise hour and sunset hour are determined as a function of the site latitude and the day of the year.

Moreover, twenty different Threshold Temperatures (TT) from 3 to 22ºC were used to obtain the optimum threshold value required to identify the full flowering days; the threshold temperature values were considered as those temperatures above which the amount of "useful heat" is accumulated for the development of olive flower structures in any geographical area.

The determination of the most suitable TT for heat accumulation in each olive grove and the evaluation of the different GDD calculation methods were carried out through the method of the RMSE considering its reliability in the threshold temperature estimation [28].

Finally correlation and regression analyses were carried out among the principal geographical parameters of every study area (Altitude, Latitude, Longitude and Sea-distance of the stations) and the best TT recorded.

Meteorological data. Minimum and maximum temperatures obtained from 6 meteorological stations located next to the 6 olive groves were used to calculate GDD. The 3 Italian stations were provided by the Agrometeorological National Network (RAN), while the Spanish meteorological data were provided by the Plant Health Service of the INIA (National Institute of Agronomic Research). The height of each meteorological station was that standardised by each national network.

RESULTS

Figure 2 shows the flowering maximum dates in the 6 areas of the two regions studied. Generally, a delay of 10-15 days in the Spanish region compared to the Italian olive groves was observed in the first years, while since 2003 the differences were reduced. All study areas showed similar flowering dates in the first 2 years while an advance was observed in 2001 and 2002. The advance recorded in 2001 was particularly evident in Agrigento and Castro stations, where it was of about 12 and 10 days respectively in comparison to the other areas. In Messina, the maximum pollination was recorded with a large delay during 2003 and 2004 in comparison to the preceding years, probably due to a particular climatic trend characterized by a warm year (2001) and by two colder years (the last two).

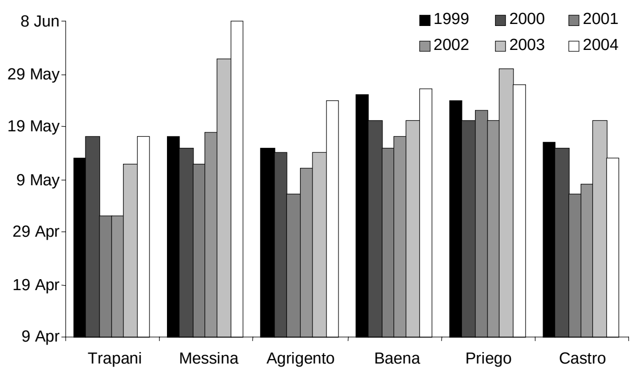


Figure 2. Flowering maximum dates in the 6-year period for each station.

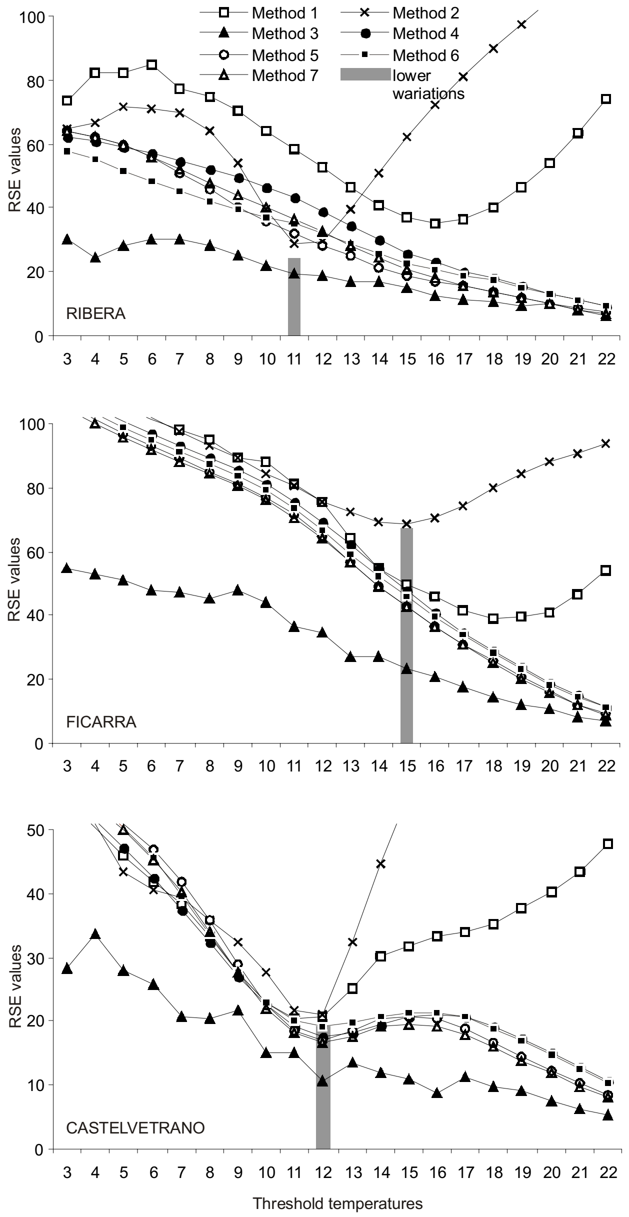


Figure 3. Threshold temperatures determination by RSME with different GDD methods for the Italian stations.

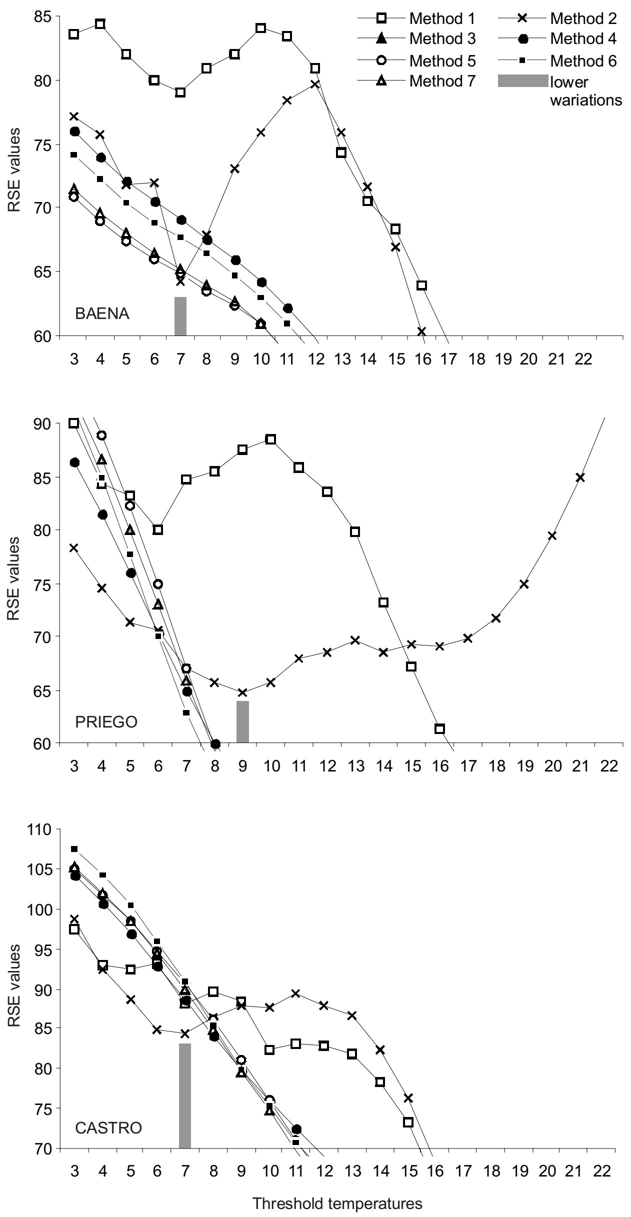


Figure 4. Threshold temperatures determination by RSME with different GDD methods for the Spanish stations.

In Figure 3 the Root Square Mean Errors considering the GDD amounts until the maximum flowering dates are reported for the Italian stations. In the Figure it is possible to note that in general all the GDD calculation methods evidence a particular trend of the standard deviations, the values decrease at the TT increment in relation to the calculation formula, only for two methods the standard deviations reach a minimum value and rise again with higher TT. This mathematical occurrence permits to identify the TT which minimizes the inter-annual variances. In this manner, the 2nd method (Single Sine) was considered as the best in relation to its trend and low minimum values recorded.

The lower variations were carried out in correspondence of a 11ºC TT in the Agrigento area, of a 15ºC TT in the Messina area and in correspondence of a 12ºC TT in the Trapani area.

In Figure 4 the RSME characterized by different TT and GDD methods are shown for the Spanish areas. The trend phenomena evidenced above by GDD methods are carried out even in these areas, and the single sine method is confirmed as the more interpretative of the climate-plant relationships. The best TT for the Baena station is represented by 7ºC, that for Priego by 9ºC and for the Castro area by 7ºC.

In Table 1 the correlation analysis among the local geographical characteristics of all the study areas and the best TT resulting from the above climatic investigation are shown.

Table 1. Correlation analysis among geographical parameters and the best threshold temperatures (TT).

	TT	Longitude	Latitude	Altitude	Sea-distance
TT	1.00				
Longitude	0.90	1.00			
Latitude	0.78	0.47	1.00		
Altitude	-0.56	-0.52	-0.42	1.00	
Sea-distance	-0.83	-0.98	-0.35	0.41	1.00

Table 2. Regression analysis among the best TT as dependent variable and longitude/latitude, as independent.

TT ~ Longitude + Latitude				
	Value	Std. Error	t value	Pr (>|t|)
(Intercept)	-237.500	60.310	-3.937	0.029
Longitude	0.216	0.035	6.061	0.009
Latitude	6.549	1.603	4.084	0.026

Residual standard error: 1.1 on 3 degrees of freedom
Multiple R-Squared: 0.984
F-statistic: 48.84 on 2 and 3 degrees of freedom, the p-value is 0.005

The higher correlation coefficient (0.90) was carried out considering the longitude of the different stations; the second high value (-0.83) was that linked to the sea-distance values. Other influencing parameters at a lower level of significance are latitude and altitude in decreasing importance; moreover, the latitude parameter influenced sufficiently the TT determination while the altitude resulted is not being very important with an r-value of -0.56.

The low correlation value of the altitude is determined by the contradictory results carried out in Italy with the Messina station (high altitude - high TT) and in Spain with the Priego station (high altitude - low TT).

To test the effective significance of the parameter longitude as the best geographic parameter in comparison to the TT specification, a regression analysis was realized (Tab. 2); the results evidence both the high explained variance (R^2=0.98) and the great significance of the independent variables. In the regression, even latitude obtained a high significance level although less than for longitude.

DISCUSSION

Several authors have reported a gradual delay in olive tree flowering from western to eastern areas [9, 12, 17]. However, a different flowering trend has been observed in the present study. Mycking [23] highlighted that continental species are more vulnerable than coastal species due to biometeorological conditions such as more inland frequent temperature fluctuations (i.e. frosts). This fact may explain the advance in flowering reported for the Italian areas due to the insular nature of Sicily, which has more stable conditions than the more continental climate characteristic of Spanish olive groves. In addition, similar phenological differences in terms of the timing of olive flowering in Cordoba due to the topography have been reported previously by Fornaciari *et al.* [12].

The use of heat units to determine the most suitable threshold temperature for a specific species has been widely reported. Some researchers have determined the threshold temperatures of several species by means of GDD computation [29, 28]. In California, a more suitable threshold temperature interval of 10–13ºC in olive trees grown in a glasshouse was obtained. Alcalá & Barranco (1992) determined a threshold temperature of 12.5ºC for the World Collection of olive cultivars within the city of Córdoba (Spain) located in the termo-mediterranean bioclimatic belt. The same threshold temperature was also obtained by Galán *et al.* (2001) in the city of Córdoba using aerobiological data. In the present paper, most of the Spanish olive groves showed threshold values between 7–9ºC.

The fact that all the Spanish sampling sites were located in the countryside, far from the city of Córdoba (Spain), within the meso-mediterranean bioclimatic step, might be the main reasons for the lower threshold temperatures obtained compared to those reported by Alcalá & Barranco [1] and Galán *et al.* [16]. This fact has been also reported by Galán *et al.* [17] in the Andalusia region.

The low correlation coefficient of the latitude parameter in comparison to the longitude can be related to the fact that all the study stations were chosen in a restricted latitude range (≈ 38°-37.4° North).

The level of continentality is reflected in a higher temperature range which can explain the lower TT of the Spanish compared to the Italian groves. With respect to this, a lower minimum temperature could condition the threshold temperature of any region.

REFERENCES

1. Alcalá AR, Barranco D: Prediction of flowering time in olive for the Cordoba Olive Collection. *Hortscience* 1992, **27(11)**, 1205-1207.
2. Allen JC: A modified sine wave method for calculating degree days. *Environ Ent* 1976, **5**, 388-396.
3. Bartolini G, Prevost G, Messeri C, Carignani G: Olive germplasm: cultivars and world-wide collections. (in press)
4. Candau P, González Minero FJ, Morales J, Tomas C: Forecasting olive (*Olea europaea* L.) crop production by monitoring airborne pollen. *Aerobiologia* 1998, **14**, 185-190.
5. Cenci CA, Pitzalis M, Lorenzetti MC: Forecasting anthesis dates of wild vegetation on the basis of thermal and photothermal indices. **In:** *Phenology in Seasonal Climates I*, 93-104. Backhuys Publishers, Leiden (The Netherlands) 1997.
6. Cesaraccio C, Spano D, Duce P, Snyder RL: An improved model for determining degree-day values from daily temperature data. *Int J Biometeorol* 2001, **45**, 161-169.
7. Consejo Oleícola Internacional: *Enciclopedia Mundial del Olivo*. Plaza & Janés Editores S.A., Barcelona (Spain) 1996.
8. D'Amato G, Liccardi G: Pollen-related allergy in the European Mediterranean area. *J Allergy Clin Immunol* 1994, **83**, 116-122.
9. Díaz de la Guardia C, Galán C, Domínguez E, Alba F, Ruiz L, Sabariego S, Recio Criado M, Fernández-Gonzalez D, Mendez J, Vendrell M, Gutierrez-Bustillo M: Variations in the main pollen season

of *Olea europaea* L. at selected sites in the Iberian Peninsula. *Polen* 1999, **10**, 103-113.

10. Domínguez E, Infante F, Galán C, Guerra F, Villamandos F: Variation in the concentrations of airborne *Olea* pollen and associated pollinosis in Córdoba (Spain); a study of the ten years period 1982-1991. *J Investig Allergol Clin Immunol* 1993, **3(3)**, 121-129.

11. Florido JF, González Delgado P, Saenz de San Pedro B, Quiralte J, Arias de Saavedra JM, Peralta V, Ruiz Valenzuela L: High levels of *Olea europaea* L. pollen and relation with clinical findings. *Int Arch Allergy Immunol* 1999, **119**, 133-137.

12. Fornaciari M, Galán C, Mediavilla A, Domínguez E, Romano B: Aeropalynological and phenological study in two different mediterranean olive areas: Córdoba (Spain) and Perugia (Italy). *Plant Biosystems* 2000, **134(2)**, 199-204.

13. Fornaciari M, Orlandi F, Romano B: Phenological and Aeropalynological survey in an olive orchard in Umbria (Central Italy). *Grana* 2000, **39**, 246-251.

14. Fornaciari M, Galán C, Romano B, Domínguez E: Aerobiology and olive growing. *Olivae* 2001, **89**, 48-50.

15. Fornaciari M, Pieroni L, Orlandi F, Romano B: A new approach to consider the pollen variable in forecasting yield models. *Economic Botany* 2002, **56(1)**, 66-72.

16. Galán C, García-Mozo H, Cariñanos P, Alcázar P, Domínguez-Vilches E: The role of temperature in the onset of the *Olea europaea* L. pollen season in southwestern Spain. *Int J Biometeorol* 2001, **45**, 8-12.

17. Galán C, García-Mozo H, Vázquez L, Ruiz L, Díaz de la Guardia C, Trigo MM: Heat requirement for the onset of the *Olea europaea* L. pollen season in several sites in Andalusia and the effect of the expected future climate change. *Int J Biometeorol* 2005 (in press).

18. Garcia-Mozo H, Galán C, Aira MJ, Belmonte J, Díaz de la Guardia C, Fernández D, Gutierrez AM, Rodríguez FJ, Trigo MM, Domínguez-Vilches E: Modelling start of oak pollen season in different climatic zones in Spain. *Agr For Meteorol* 2002, **110**, 247-265.

19. González Minero FJ, Candau P, Morales J, Tomas C: Forecasting olive crop production based on ten consecutive years of monitoring airborne pollen in Andalucía (southern Spain). *Agric Ecosyst Environ* 1998, **69**, 201-215.

20. Hartmann HT, Whisler JE: Flower production in olive as influenced by various chilling temperature regimes. *J Am Soc Hortic Sci* 1975, **100(6)**, 670-674.

21. Lieth H: *Phenology and Seasonality Modelling.* Springer-Verlag, Berlin-Heidelberg-New York 1974.

22. Maillard R: Stades riperes de l'olivier. *L'olivier* 1975, 24-25.

23. Mycking T: Dormancy, budburst and impacts of climatic warming in coastal-inland and altitudinal Betula pendula and B. pubescens ecotypes. **In:** *Phenology in Seasonal Climates I*, 51-66. Backhuys Publishers, Leiden (The Netherlands) 1997.

24. Orlandi F, Fornaciari M, Romano B: The use of phenological data to calculate chilling units in *Olea europaea* L. in relation to the onset of reproduction. *Int J Biometeorol* 2002, **46**, 2-8.

25. Parton WJ, Logan JA: A model for diurnal variation in soil and air temperature. *Agric For Meteorol* 1981, **23**, 205-216.

26. Pellizzaro G, Spano D, Cann A, Cesaraccio C: Calcolo dei Gradi-Giorno per la previsione delle fase fenologiche nell'actinidi. *Italus Hortus* 1996, **3(5)**, 24-30.

27. Rallo L, Martin GC: The role of chilling in releasing Olive floral buds from dormancy. *J Am Soc Hortic Sci* 1991, **116(6)**, 1058-1062.

28. Snyder RL, Spano D, Cesaraccio C, Duce P: Determining degree-day thresholds from field observations. *Int J Biometeorol* 1999, **42**, 177-182.

29. Spano D, Cesaraccio C, Duce D, Zinder RL: Phenological stages of natural species and their use as climate indicators. *Int J Biometeorol* 1999, **42**, 124-133.

30. Wielgolaski FE: Starting dates and basic temperatures in phenological observations in plants. *Int J Biometeorol* 1999, **42**, 158-168.

31. Wilkerson GG, Jones JW, Boote KJ, Ingram KT, Mishoe JW: Modelling soybean growth for crop management. *Trans ASAE* 1983, **26**, 63-73.

32. Wit CT de, Goudriaan J, Laar HH van: *Simulation of assimilation, respiration and transpiration of crops.* Center for Agricultural Publishing and Documentation, Wageningen, The Netherlands 1978.

33. Zalom FJ, Goodell PB, Wilson LT, Barnett WW, Bentley WJ: *Degree-days: the calculation and use of heat units in pest management.* DANR Leaflet 21373, University of California 1983.