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WEATHER VARIABILITY EFFECT ON PHENOLOGICAL EVENTS IN A MEDITERRANEAN-TYPE CLIMATE

Pierpaolo Duce*[1], Carla Cesaraccio[1], Donatella Spano[2], Richard L. Snyder[3]
[1]CNR – IBIMET, Institute of Biometeorology, Agroecosystem Monitoring Lab., Sassari, Italy
[2]DESA, University of Sassari, Sassari, Italy
[3]University of California. Atmospheric Science, Davis, California

1. INTRODUCTION

To assess the possible effects of weather variability on development of Mediterranean ecosystems, it is important to understand the climatic factors driving the phenology. In a Mediterranean-type climate, seasonality mainly depends on temperature and water availability. To quantify the effects of weather variability on development, different phenological models are needed to identify the causal relation between the relevant climatic driver and the phenological response of plants. In recent decades, several studies were conducted to investigate the phenological behaviour of various species in different Mediterranean climates (Correia et al., 1992; de Lillis and Fontanella, 1992; Kummerow et al., 1981; Moll, 1987; Montenegro et al., 1979; Mooney and Kummerow, 1981; Mooney et al., 1974). Most phenological models use temperature-based heat unit accumulation (e. g., degree-days) as a measure of developmental rates. Although the effect of rainfall and, hence, water stress on phenology is also important in arid regions, the relation between phenology and duration and intensity of drought has received little attention (Loustau et al., 1996; Spano et al., 1999). Rainfall and drought significantly influence the flowering dates of non-Mediterranean species (Spano et al., 1999) and accounting for drought is clearly important. This was also recognized by Kramer et al. (2000), who developed a water-driven phenological model for a maritime pine forest in southern France. The objectives of this study were to evaluate both temperature and soil water availability effects on the flowering date of several natural plant species growing in a Mediterranean-type climate and to explain year-to-year variation of the flowering date.

2. MATERIALS AND METHODS

The study was conducted in the Phenological Research Garden located within the Experimental Farm at the University of Sassari in Oristano, Sardinia, Italy (39° 53’ N, 8° 37’ E, 11 m a.s.l.) during the period 1986-1999. Phenological data were collected weekly on four non-native species (*Cercis siliquastrum* L., *Robinia pseudoacacia L., Salix chrysochoma* L., and *Tilia cordata* L.).

Temperature data were employed to calculate cumulated degree-days (*CDD*) from 1 January until flowering using hourly mean temperature values obtained from an empirical model that approximates daily temperature curve from daily maximum and minimum air temperatures (Cesaraccio et al., 2001). The root mean square error (*RMSE*) of the predicted minus observed days over all of the years for each species was calculated.

Drought conditions of the experimental period (14 years) were evaluated by calculating the available water for each day using a simple soil-water balance model based on measured rainfall and estimated evapotranspiration rate (Reed et al., 1997).

3. RESULTS AND DISCUSSION

Statistics on the flowering date occurrence and the number of *CDD* using the 0 °C lower temperature threshold are reported in Table 1 for the 1986-1999 period. The results showed a large year-to-year variation by species in terms of observed flowering dates and *CDD* values. This is an indication that other factors in addition to heat units affected plant development.

Table 1. Flowering date occurrence (day of the year, *DOY*) and cumulative degree-day (*CDD*) values from 1 January. The mean, standard deviation (s) and coefficient of variation (*CV*) are reported.

	DOY			*CDD*		
	mean	s	*CV*	mean	s	*CV*
Cercis s.	97	8	8	992	138	14
Robinia p.	119	8	6	1294	141	11
Salix c.	98	28	29	1063	565	53
Tilia c.	143	20	14	1746	366	21

Accumulated rainfall amount (*SR*) was calculated from the day when soil was at the maximum water content (usually December or January) until the earliest flowering date for each species. The analysis of the residuals from the mean *CDD* values showed that the relation between *CDD* and flowering occurrence of all species was strongly affected by *SR*, as shown in Figure 1 for *Cercis siliquastrum*. The other species had unique relationships between residuals and *SR*.

The equations relating residuals to *SR* were

**Corresponding author address*: Pierpaolo Duce, CNR-IBIMET, Institute of Biometeorology, Agroecosystem Monitoring Lab., Via Funtana di Lu Colbu 4/A, 07100 Sassari, ITALY; e-mail: duce@imaes.ss.cnr.it.

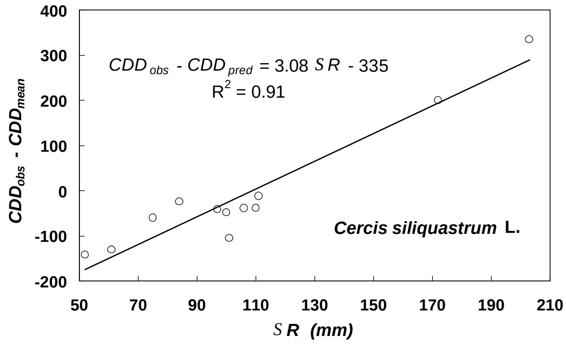

Figure 1. Linear relation between residuals of *CDD* values from the mean value ($CDD_{obs} - CDD_{mean}$) and rainfall amount (*SR*) accumulated from the period when soil was at the maximum water content to the earliest flowering date for *Cercis siliquastrum* L.

employed to recalculate degree-days (CDD_{corr}) and obtain corrected flowering dates. In addition, the mean flowering dates of the period were used as an estimate of the flowering events. Table 2 shows a comparison of the methods in terms of accuracy of the prediction. The *RMSE* values indicate how closely the predicted days match with the observed number of days.

Table 2. Root mean square error (*RMSE*) between observed and predicted days using the cumulative degree-day model (*CDD*), the mean flowering date (DOY_{mean}), and the cumulative degree-day model corrected for *SR* (CDD_{corr}). *N* is the number of years.

	RMSE (days)			*N*
	CDD	DOY_{mean}	CDD_{corr}	
Cercis s.	9.7	7.9	3.3	12
Robinia p.	8.9	7.5	4.2	14
Salix c.	33.3	27.5	13.4	12
Tilia c.	18.1	18.8	10.5	11

The accuracy of the *CDD* model seems to be strongly affected by the interannual variability in weather conditions. The prediction obtained using simply the mean date of the flowering event showed similar or better *RMSE* values than the heat unit accumulation model. Better accuracy was obtained adjusting the *CDD* model taking into account the correlation between residuals of *CDD* values from the mean value and rainfall amount (*SR*) accumulated from the period when soil was at the maximum water content to the earliest flowering date.

4. CONCLUSIONS

The results showed that the accuracy of CDD model in predicting flowering dates was generally poor and variable for non-native species. A significant improvement in the prediction of the flowering date was obtained by adjusting the *CDD* model for rainfall amount accumulated from the period when available soil water content was at maximum to the earliest flowering date typical of each species. In general, the flowering dates were postponed when the soil water was not limiting and flowering occurred earlier during drought years.

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