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Modelling olive phenological response to weather and topography

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ABSTRACT

A detailed analysis was made of the response of olive floral phenology to climate and topography in southern Spain. Field phenological, topographical and meteorological data collected at 12 sampling sites in the province of Córdoba over a 17-year period (1996–2012) were statistically analyzed and used to model local olive phenological behaviour.

The study sought to determine: (1) the optimal frequency of phenological sampling during the reproductive period; (2) the major topographical parameters governing local olive reproductive phenology; and (3) the most influential meteorological variables. Findings for the Sign test indicated that weekly sampling yielded accurate results. Correlation and multiple linear regression analysis revealed that altitude and percentage eastward slope were the most influential topographical factors; a positive correlation was detected between delays in phenophases onset and increased altitude and eastward orientation. Correlation and partial least square regression analysis identified air temperature, rainfall, crop evapotranspiration and solar radiation as the major weather factors influencing local olive phenology.

1. Introduction

Phenology was initially defined as "the study of the timing of recurring events, the causes of their timing with regard to biotic and abiotic forces, and the interrelation among phases of the same or different species" (Lieth, 1974). More recent definitions, however, stress the important influence of the environment; Schwartz (1999), for example, notes that "phenology includes the study of periodic events as influenced by the environment, especially temperature changes driven by weather and climate".

Plant reproductive phenology is heavily dependent on environmental conditions. Close examination of phenological behaviour, and of the bioclimatic factors influencing it, is of particular value in areas that are theoretically affected by climate warming, such as the Mediterranean region. This is especially true for major crops such as the olive, *Olea europaea* L., which is grown today not only over much of the Mediterranean basin, but also in south-western Asia and in the Americas, including California, Chile and Argentina (Barranco et al., 2008). The olive is clearly a key crop in agricultural, socioeconomic and environmental terms (Lavee, 1996). It is also important for health reasons the consumption of olive oil is seems to be regarded as beneficial (Tuck and Hayball, 2002), while olive pollen is associated with widespread allergic reactions (D'Amato et al., 2007; Barber et al., 2008). Andalusia region (southern Spain) is the world's largest olive-producing area, accounting for 61% of the total planted to olives in Spain; olive groves are concentrated mainly in provinces such as Jaen and Córdoba (Andalusia Statistical Yearbook, 2011).

Annual olive vegetative and reproductive cycles – and therefore annual fruit yield, which is directly related to flowering intensity (Fornaciari et al., 2005; Galán et al., 2008; García-Mozo et al., 2008; Orlandi et al., 2010a) – seems to be strongly influenced by environmental conditions. The complex phenological response to milder winter temperatures provides a reliable bio-indicator of the impact of climate change in a number of plant species (Osborne et al., 2000; Lambs et al., 2006; Menzel et al., 2006; García-Mozo et al., 2010; Gunderson et al., 2010; Xiao et al., 2013). The present study sought to examine the response of olive crops in the province of Córdoba to weather-related and topographical variables, using field phenological, topographical and meteorological data collected over a 17-year period from 1996 to 2012. Bud break in this area starts in around March, and the main flowering period is usually recorded in May, although changing weather conditions often prompt variations in timing, which have become particularly apparent over recent decades (Galán et al., 2005; Bonofiglio et al., 2008; García-Mozo et al., 2010; Orlandi et al., 2013a).

Although a combination of photoperiod and temperature determines the olive flowering period, it has been shown that temperature largely controls the reproductive development of the olive

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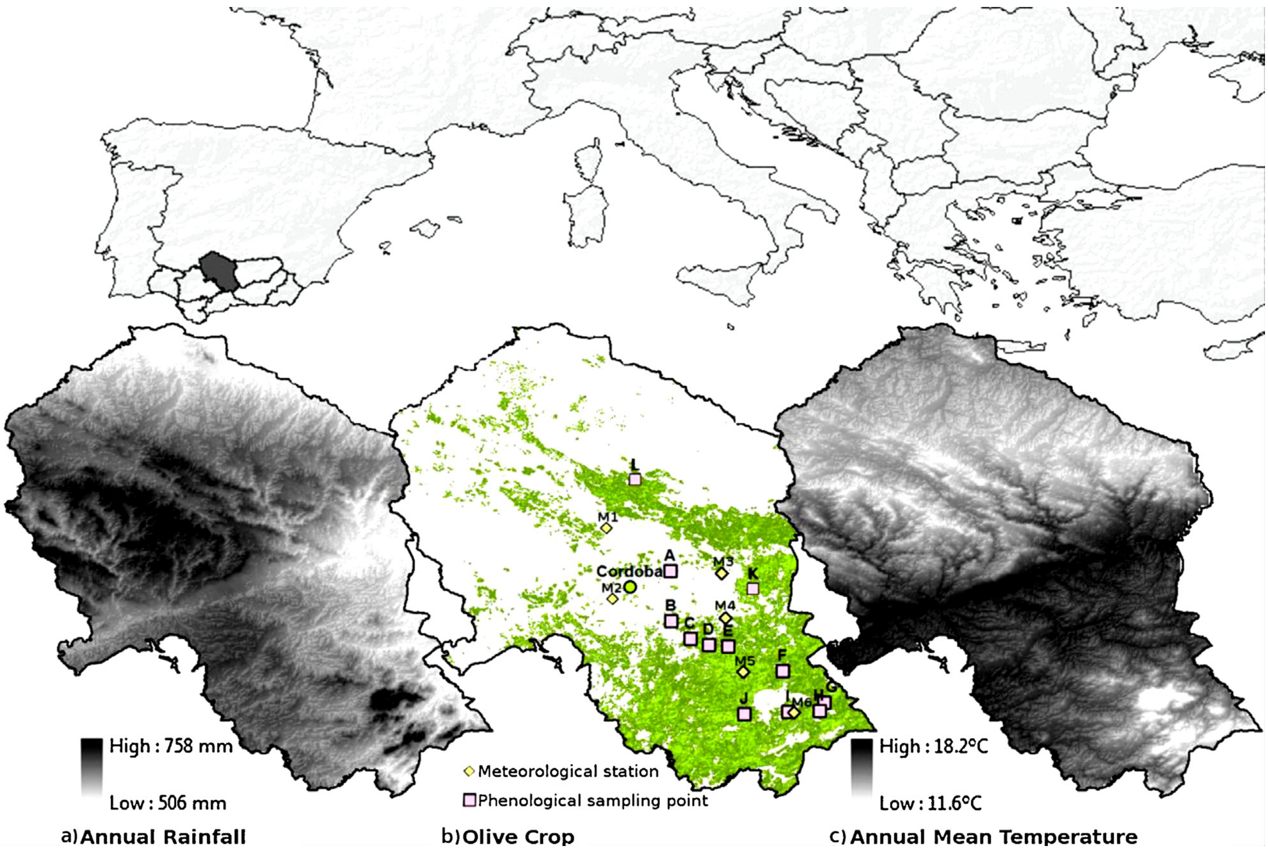

Fig. 1. Location of Córdoba province. (a) Annual rainfall distribution in Córdoba province. (b) Olive crop distribution, location of sampling sites (A–L) and weather stations (M1–M6). (c) Annual mean temperature distribution.

tree, especially during pre-flowering and anthesis (Galán et al., 2001, 2005; Melo-Abreu et al., 2004; García-Mozo et al., 2009; Sicard et al., 2012). Floral induction takes place during the previous summer, and a chilling period is required in order for buds to break winter dormancy (Rallo and Martin, 1991; Orlandi et al., 2006; Andreini et al., 2008). Subsequently, a warm period is required in order for the plant to accumulate sufficient forcing units physiological heat to enable flower development (Galán et al., 2005; Orlandi et al., 2010b). Logically, topography also plays an important role in phenological development, which varies as a function of different photoperiods and weather conditions (García-Mozo et al., 2006; Aguilera and Ruíz-Valenzuela, 2009).

The phenological characteristics of any area are dependent on local climate, which is in turn governed both by macroclimatic conditions, defined by variables such as latitude, and by determinants of microclimatic conditions such as topography. Within a reduced study area, knowledge of microclimatic conditions is essential for a full understanding of differences in reproductive phenology. In order to identify the variables responsible for variations in phenotypic expression in the province of Córdoba, an analysis was made of the correlations between several topographical and weather-related variables and the specific phenological features of various sampling sites.

The main goal of the study was to model olive floral phenological behaviour, taking into account variations in the main factors influencing that behaviour at different sites in the province of Córdoba (Spain) over the last 17 years. Specifically, the study sought to determine: (1) the optimal frequency of phenological sampling during the reproductive period; (2) the major topographical variables governing local olive reproductive phenology; and (3) the most influential weather-related variables.

2. Materials and methods

2.1. Area of study and weather data

The study was carried out in the province of Córdoba, Andalusia (southern Spain) (Fig. 1). The province is located in the Mediterranean region. Local vegetation and crops are adapted to drought periods that last between two and nine months every year. Córdoba city is located in the valley of the Guadalquivir river. The annual mean temperature is 17.8 °C and the annual average rainfall is 621 mm; weather conditions vary greatly year-on-year. Moreover, the continental effect is reflected in particular thermal and rainfall regimes: low rainfall, low relative humidity, and wide daily and annual temperature ranges, are characteristic of the study area (Domínguez-Bascón, 2002). Torrential rains usually occur. Peak daily temperatures are recorded in the afternoon and minimum temperatures at dawn.

The study area, the olive crop distribution, and the location of sampling sites and weather stations, are shown in Fig. 1. This figure also shows variations in annual mean temperature and rainfall within the province. The characteristics of sampling sites are shown in Table 1. The main olive cultivar in the Cordoba province is "Hojiblanca", except for some minor areas in the south of the province, with moreover "Hojiblanca", "Picudo" cultivar is also present and in which are located some of our sampling points (namely Cabra, Carcabuey, Priego and Fuente Tójar).

Four topographical variables were analyzed for each site: altitude (m), maximum slope inclination (%) and maximum slope orientation (%) from South to North and from East to West. Slope orientation ranged from 0% to 100%; values close to 100% indicated maximum South and East orientation, while values close to 0% indicated North and West orientation.