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Short communication

A long-term study on the effect of agroclimatic variables on olive scab in Spain

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ABSTRACT

Olive scab (OS), caused by *Venturia oleaginea*, is the most widespread disease in all olive growing regions. However, there is not much information about critical agroclimatic conditions for OS development under natural conditions. To cover this lack of knowledge, the OS severity (OSS) of 92 epidemics, from 14 locations, 16 years and 11 olive cultivars, was annually evaluated. Epidemics were divided in three periods of years: from 1994 to 1998 (period I), from 2002 to 2008 (period II) and from 2010 to 2013 (period III). OSS was compared among periods. Also, Pearson's (r) or Spearman's rank (ρ) correlation coefficients were calculated between OSS and monthly weather variables, cultivar resistance categories and OSS value in the previous epidemic year. The OSS in period III was higher than the OSS in the other two periods. Resistance categories and OSS in the previous year were highly correlated with OSS. Relative humidity (RH) and rainfall (R) were the weather variables positively correlated with OSS in all periods. OSS in the previous year, daily average RH (RH_m) in July, average of daily maximum temperature (T_{mx}) in November, average of daily maximum RH (RH_{mx}) in December and average of daily minimum temperature (T_{mn}) in March were selected as agroclimatic variables to develop a linear regression model that relates them with OSS. The present study provides relevant information about the long-term factors that affect the OS development.

1. Introduction

Olive scab (OS), caused by *Venturia oleaginea* (Castagne) Rossman et al., is the most widespread disease in all olive growing regions (Graniti, 1993; Miller, 1949; Trapero et al., 2017). The disease, which is also called peacock's eye or leaf spot, was recognized firstly in 1845, when its causal agent was described as *Cycloconium oleaginum* (Schubert et al., 2003). *Fusicladium oleagineum* (González-Domínguez et al., 2017; Roubal et al., 2013; Viruega et al., 2011) and *Spilocaea oleagina* (Moral et al., 2015; Obanor et al., 2008; Viruega et al., 2013) are the most commonly used synonyms for this pathogen, although the name *Venturia oleaginea* has recently been proposed based on its genetic identification (Rossman et al., 2015). The species *V. oleaginea* is a biotrophic fungus that hardly grows in culture medium (Petri, 1913; Saad and Masri, 1978; Viruega et al., 2011). The main symptom of the disease is the appearance of circular lesions with a chlorotic halo on the upperside of the olive leaves. Lesions change from a typical black scab to a whitish scab when high temperatures occur and the cuticle of infected leaves separates from the epidermal cells (Graniti, 1993; Viruega et al., 2013). Under moist conditions, small sunken brown lesions may appear on the petioles, fruit peduncles and fruit (Graniti, 1993), resulting in fruit drop and reduced oil yield (Verona and Gambogi, 1964; Viruega et al., 2011). Olive scab is particularly severe in high-density plantations with susceptible cultivars and with favorable weather conditions (Graniti, 1993). Traditionally, OS has been controlled using a combination of cultural measures and fungicide applications (Trapero et al., 2017). Timing of fungicide applications is essential for effective disease control (Roca et al., 2007; Teviotdale et al., 1989; Trapero and Roca, 2004). Springs, and sometimes early autumn, are commonly considered as critical periods for infection due to the presence of highly susceptible young leaves and favorable weather conditions (Obanor et al., 2008, 2011; Viruega et al., 2011). Although rain is considered the main spore dispersal agent (Lops et al., 1993; Roubal et al., 2013; Viruega et al., 2013), the Psocoptera insect *Ectopsocus briggsi* has been described as

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possible vector of *V. oleaginea* over longer distances (De Marzo et al., 1993). Furthermore, spores can be spread by the wind attached to leaf trichomes that work like a parachute (Viruega et al., 2013).

The effect of weather conditions on the infection has been widely studied during the last several years. In controlled (Obanor et al., 2011; Viruega et al., 2011) and field experiments (Roubal et al., 2013), infection of *V. oleaginea* occurred at a temperature range of 0–27 °C (optimum at 15–20 °C) with > 12 h of wetness. Dry periods can stop the infection process, particularly if they occur within 12 h after conidial germination (Obanor et al., 2011). Cultivar susceptibility (Moral et al., 2015; Zine El Aabidine et al., 2010), leaf age and inoculum dose also play a key role in the infection process (Obanor et al., 2011; Viruega et al., 2011). At the end of the latent period, *V. oleagina* conidiophores erupt from the cuticle of upper leaf surface and produce conidia (Graniti, 1993). The length of latent period varies depending on the number of rainy days, temperature and leaf age, but it is rarely shorter than 30 days (Chen and Zhang, 1983; Roubal et al., 2013; Viruega et al., 2011).

A long-term study on the effect of environmental variables on OS disease progress was conducted to extend the current knowledge on critical conditions that determine the OS severity (OSS). The main goal of this study was to elucidate which are the more relevant variables that influence the disease severity and design general recommendations about timing of fungicide applications.

2. Materials and methods

2.1. Experimental fields

OSS was evaluated in 92 epidemic events, which occurred in 14 locations in the Andalusia region (southern Spain) for 16 years: 1994 to 1998 (n = 40), 2002 to 2008 (n = 17) and 2010 to 2013 (n = 35). All the orchards were between 10 and 25 years old, planted on 7–10 × 7–10 m row spacing, with one trunk per tree, rain-fed, and pruned every three years (Table 1; Supplementary Table). Two copper-based treatments (Bordeaux mixture, Caldo Bordelés Vallés, Industrias Químicas Vallés, copper calcium sulfate WP (20% of metallic copper) were applied at 2 kg Cu ha^{-1} in all the fields in spring and autumn (two per year) to control extremely severe epidemics of olive scab, cercospora leaf spot and anthracnose, caused by *V. oleaginea*, *Pseudocercospora cladosporioides*, and *Colletotrichum* spp., respectively (Trapero et al., 2017). These fungicide applications were necessary to prevent damage to the olive canopy in the experimental and commercial fields, which could pose a risk to the success of this study.

Data of air temperature (T, °C), relative humidity (RH, %), and total rainfall (R, mm) were registered daily from the nearest meteorological stations, located in a range of 0–15 km away the orchards. Weather data were used to calculate monthly weather variables, measured as average of maximum, minimum and mean daily values for each month (T_{mx}, T_{mn}, T_m, RH_{mx}, RH_{mn}, RH_m) or accumulated monthly rainfall (R). Monthly weather variables were calculated from April of the previous year (n-1) to March of the OSS measurement year (n).

Table 1
Number of olive scab epidemics studied according to the cultivar, resistance category, orchard and time period.

Cultivar	Resistance category[a]	Number of orchards[b]	Time period[(c)] I	II	III	TOTAL
Frantoio	1	1	1	2	3	6
Lechín	1	2	5	0	0	5
Leccino	2	1	0	0	1	1
Megaritiki	2	1	1	0	0	1
Arbequina	3	5	5	2	9	16
Picudo	3	1	0	2	0	2
Hojiblanca	4	5	5	3	3	11
Cornicabra	5	3	3	0	0	3
Manzanilla de Sevilla	5	4	7	0	1	8
Meski	5	2	5	0	1	6
Picual	5	10	8	8	17	33
TOTAL	-	14	40	17	35	92

[a] Cultivar resistance category from 1 (highly resistant) to 5 (highly susceptible), according to Trapero et al. (2017).
[b] There were eleven olive cultivars planted in fourteen selected olive orchards (commercials and experimental). Frequently, there was more than one olive cultivar per orchard.
[c] Three time periods were evaluated: I (1994–1998), II (2002–2008) and III (2010–2013).

Table 2
Pearson´s correlation coefficients of agroclimatic variables with significant influence (P < 0.05) on the olive scab severity (OSS).

Variable type	Month	Variable[a]	Association coefficient value[b]
Agronomic	–	OSS_{n-1}[c]	0.629**
		Cultivar Resistance[d]	0.498***
Climatic	May	RH_{mx}	0.463*
	July	RH_{mx}	0.541**
		RH_{mn}	0.513*
		RH_m	0.584**
		R	0.671***
	August	RH_{mx}	0.485*
	September	RH_{mx}	0.430*
	November	RH_{mx}	0.557**
		RH_m	0.486*
		R	0.460*
	December	RH_{mx}	0.571**
		RH_{mn}	0.520*
		RH_m	0.652**
	January	RH_{mx}	0.578**
		RH_{mn}	0.472*
		RH_m	0.622**
	February	RH_{mx}	0.450*
	March	RH_{mx}	0.448*
		RH_{mn}	0.418*

*P < 0.05; **P < 0.01; ***P < 0.001.
[a] R is the monthly accumulated rainfall, $RH_{mx,}$ RH_{mn} and RH_m are the monthly average value of maximum, minimal and average daily relative humidity.
[b] Pearson coefficient (r) were calculated for all variables except cultivar resistance, for which the Spearman coefficient(ρ) was used.
[c] Olive scab severity in the previous year.
[d] Cultivar esistance category, from 1 (highly resistant) to 5 (highly susceptible).

2.2. Disease evaluation

OSS of all epidemics were assessed at mid-April by using a 0 to 10 rating scale, where 0 = no affected leaves per tree, 1 = 1 to 3 affected leaves per tree, 2 = 1 to 3 affected leaves per each quadrant of the tree canopy and 3 = 4 to 9 affected leaves per each quadrant of the tree canopy. Higher rating values were obtained by directly estimating the percentage of affected leaves where 4 = 3.5%, 5 = 10%, 6 = 25%, 7 = 50%, 8 = 75%, 9 = 90%, and 10 = > 94% of the affected leaves or fruits (Moral and Trapero, 2009). The assessors circled the canopy of 10 olive trees, randomly selected, looking for leaves in a 1- to 2-m band above ground, so that the canopy area checked was approximately 25% of the total.

Then, the rating data of affected leaves were transformed in the proportion of affected leaves using the logistic equation developed by Moral and Trapero (2009):

$$Y = \frac{1}{1 + 3^{(7-X)}}$$