Agricultural and Forest Meteorology 271 (2019) 207–213

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet

A new aerobiological indicator to optimize the prediction of the olive crop yield in intensive farming areas of southern Spain

Fátima Aguilera*, Luis Ruiz-Valenzuela

Department of Animal Biology, Plant Biology and Ecology, Agrifood Campus of International Excellence (CeiA3), University of Jaen, 23071 Jaen, Spain

ARTICLE INFO

Keywords:
Airborne pollen
Forecasting regression model
Olive fruit production
Southern Spain

ABSTRACT

In the present study, bio-meteorological regression models for forecasting the fruit produced by the olive trees in Jaen (southern Spain), the province with the largest extension of olive groves in the world, were revised and improved. The new forecasting models were constructed using partial least-squares regression, taking the annual olive yield as the dependent variable and several aerobiological and meteorological parameters as the independent variables. The models were validated following a full cross-validation method. A 23-year period (1994–2016) was used. The number of days with pollen concentrations ≥400 pollen grains m^{-3} was revealed as a newfangled predictive variable to accurately predict the olive harvest in this area, being included in the forecasting model with the highest determination coefficient value ($R^2 = 0.89$). Weather-related variables such as the cumulative precipitation from October to December of the previous year or the mean maximum temperature from January to March were also factors of particular importance on crop production. The new model proposed provides early and effective olive crop forecasting by using independent variables which can be easily obtained towards the middle of June, also incorporating to the model the phenological variability associated with changes in the local weather. The approach shown in this study readily could be applied to any potential new situation and to be extensible to other similar olive growing areas across the Mediterranean region.

1. Introduction

Olive growing is one of the most extensively cultivated fruit crops in the Mediterranean region, considered the major source of income and employment in this area and playing a socio-economic and cultural role of great importance (Loumou and Giourga, 2003). Fruits and oil are among the oldest and the most important products, this last representing 90% of economic benefits obtained from this crop. Spain, which produces 48% of the world's total olive oil output, it is the greatest olive-growing area in the world (International Olive Council, 2018). The first largest area in Spain producing olive fruits is concentrated in the province of Jaen (southern Spain), where olive cropping systems, which include agroforestry stands, traditional groves and new intensive orchards, are of enormous importance in both economic and ecological aspects (Villalobos et al., 2006). According to Araque et al. (2002), olive groves of this province have become the most productive into the country, serving as a model in several experiments carried out throughout the Guadalquivir valley. The more than 585,000 ha of intensive monovarietal olive grove cultivation throughout this province makes Jaen a good experimental scenario for the elaboration of crop yield forecasting models (Consejería de Agricultura, Pesca y Desarrollo Rural, 2018; Villalobos et al., 2006).

Early and effective quantitative forecasting of yield has become a valuable tool in the support of farmers and all the entities involved in the olive sector. An accurate early estimate of olive crop yield has practical application in different activities such as olive oil transformation efficiency, planning harvest and storage requirements, stock management, marketing strategies, global commercial distribution, optimizing human resources necessary for the harvest and also for crop insurance purposes.

Fruit production crops have been forecasted by several methods, since the classic and frequently used method commonly denominated *aforos* and based on early visual observation prior to the harvest to more recent studies such as crop growth monitoring system models or forecasting models based on satellite measurements (Bastiaanssen and Ali, 2003; Fei et al., 2012). The use of long-term data series has been proved as a well crop forecasting technique (Aguilera and Ruiz-Valenzuela, 2014; De Boissezon, 1995; Miller, 1990; Palm, 1995; Sharman et al., 1992). The close relationship between pollen emission and fruit production has been largely studied, particularly in

* Corresponding author at: Department of Animal Biology, Plant Biology and Ecology, University of Jaen, Agrifood Campus of International Excellence (CeiA3), Campus Las Lagunillas s/n, 23071 Jaen, Spain.

E-mail address: faguiler@ujaen.es (F. Aguilera).

https://doi.org/10.1016/j.agrformet.2019.03.004
Received 2 October 2018; Received in revised form 2 March 2019; Accepted 5 March 2019

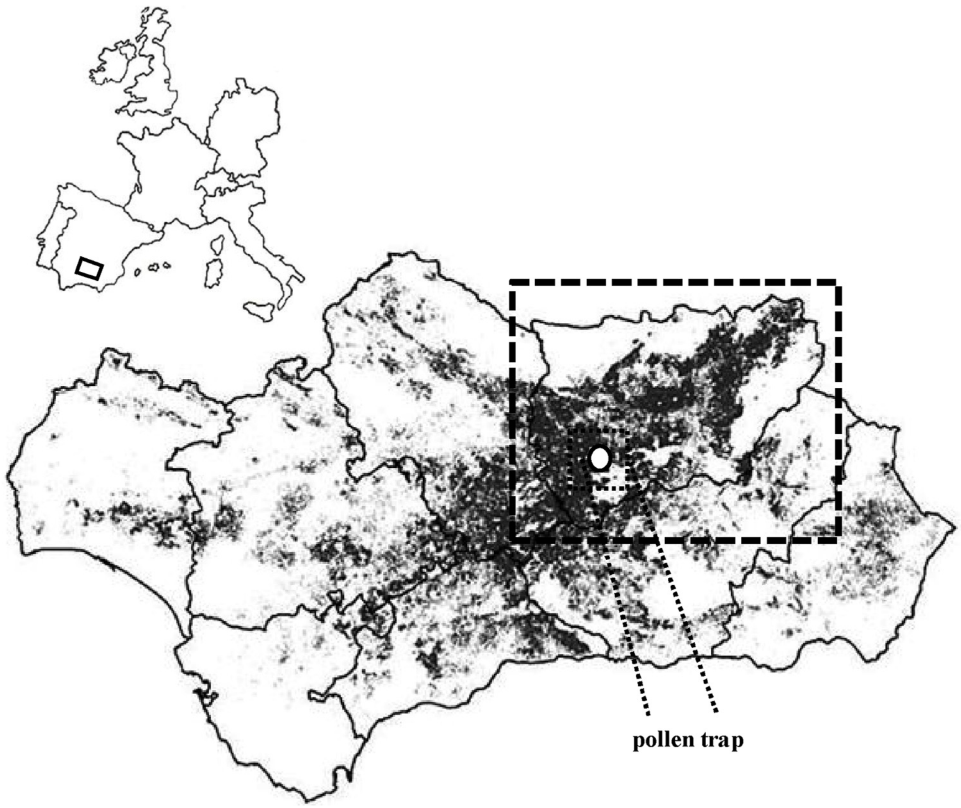

Fig. 1. Distribution of the olive groves and position of the pollen trap in the province of Jaen (southern Spain).

anemophilous crops. Many authors have demonstrated this fact with optimal results in European filbert (*Corylus avellana* L.; Lletjos et al., 1993), grape (*Vitis vinifera* L.; Baugnent, 1991; Cunha et al., 2003), holm oak (*Quercus ilex* L.; García-Mozo et al., 2012) and olive (*Olea europaea* L.; Fornaciari et al., 2002, 2005; Galán et al., 2008; García-Mozo et al., 2008; Orlandi et al., 2010; Ribeiro et al., 2007, 2017). Nevertheless, the establishment of forecasting models solely based on total airborne pollen sampling cannot be satisfactory. External parameters such as weather and agronomic conditions from previous months to the flowering period until the harvest date (water deficit, extremes temperatures or also phytopathological problems) could have a negative effect on fruit quantity and quality, increasing the inter-annual variability in the final harvest. In this sense, different studies on olive fruit production have included meteorological variables in relationship with airborne pollen concentrations to obtain more accurate estimations (Aguilera and Ruiz-Valenzuela, 2014; Galán et al., 2008; Orlandi et al., 2010; Oteros et al., 2014).

A recent study focused on the most frequent pollen types in the airborne spectrum of Jaen revealed significant changes in pollen intensity and duration of the pollen season of numerous deciduous and evergreen arboreal species during the last two decades (Ruiz-Valenzuela and Aguilera, 2018). In particular, airborne pollen trend for the olive tree is rising in line with local temperature increasing trend, while the pollen season tends to end later and last longer. Similar results have been reported in different study areas through the Iberian Peninsula (Galán et al., 2016; Ribeiro et al., 2008; Tormo-Molina et al., 2010). Fruit setting could be affected for the changes detected in the olive tree pollination process, so, these should be considered in the yield forecasting models and new biological variables should be tested. Therefore, the aims of this study were i) to test different aerobiological variables where airborne pollen intensity and duration of the pollen season are combined and related with olive fruit production to develop accurate crop forecasting models and ii) to revise and improve the bio-meteorological forecasting models developed previously in the study area.

2. Materials and methods

2.1. Study area

The study was carried out in the province of Jaen, located in the southern Spain. The climate profile is continental Mediterranean, with cold winters, hot-dry summers and marked yearly variations in weather patterns. Annual average temperature is 17.1 °C and annual average precipitation is 485 mm. The province of Jaen covers a surface are of 13,489 km^2 and has a population density of 47.93 inhabitants per km^2 (Spanish Statistical Office, 2017). Crops, mainly olive trees, cover around 49% of the total surface area, being the main economic activity in the province (Consejería de Agricultura, Pesca y Desarrollo Rural, 2018).

During the last two decades, this olive-growing area has suffered a significantly change in the olive grove system. The traditional rain fed orchard with low density (less than 100 olive trees/ha), intensive tillage, low inputs in fertilizer and pesticides and manual harvest is being substituted by new intensive (200–400 olive trees/ha) drip-irrigated plantations, with reduced tillage, high inputs and mechanical harvesting (Villalobos et al., 2006). This transition has caused a notable increase in the cultivation area and the flowering intensity of the olive, which releases large amounts of pollen grains into the atmosphere during the spring (Aguilera and Ruiz-Valenzuela, 2012; García-Mozo et al., 2008).

2.2. Forecasting models

2.2.1. Airborne pollen and meteorological data

The biological parameter considered in this study was the olive pollen captured in the atmosphere during the olive flowering period by using aerobiological monitoring. Airborne pollen data were collected

Table 1
Principal characteristics of the aerobiological variables and the olive fruit production in the study area for the period 1994–2016.

	SPIn	Pollen_200	Pollen_400	Pollen_600	Pollen_800	Production
Maximum	117,791	59	47	35	34	3,596,668
Minimum	18,625	23	14	10	8	461,002
Mean ± SD	53,466 ± 24,890	35 ± 7	27 ± 8	22 ± 6	18 ± 6	2,028,178 ± 844,098
cv	0.49	0.21	0.31	0.26	0.27	0.42

SPIn, Seasonal Pollen Integral (pollen*day m^{-3}); *Pollen_200*, defined as the number of days with pollen concentrations ≥200 pollen grains m^{-3}; *Pollen_400*, defined as the number of days with pollen concentrations ≥400 pollen grains m^{-3}; *Pollen_600*, defined as the number of days with pollen concentrations ≥600 pollen grains m^{-3}; *Pollen_800*, defined as the number of days with pollen concentrations ≥800 pollen grains m^{-3}; Production (tonnes); cv; coefficient of variation.

continuously over a 23-year period (1994–2016) using a Hirst-type volumetric pollen trap, based on the impaction process (Hirst, 1952). The monitoring station, it placed in the University of Jaen (15 m above ground level), is surrounded by olive groves (Fig. 1). The standard data management procedures were used following the recommendations and minimum requirements from the European Aerobiology Society (Galán et al., 2014).

Five aerobiological variables were calculated: a) Seasonal Pollen Integral (SPIn), obtained by summing the average daily pollen concentrations over the main pollen season (Galán et al., 2017). The start of the pollen season was defined as the first day on which at least five pollen grains m^{-3} were collected, with subsequent days at ≥5 pollen grains m^{-3} (Aguilera and Ruiz-Valenzuela, 2014). The end of the pollen season was the last day on which five pollen grains m^{-3} were collected, with the subsequent days had concentrations < 5 pollen grains m^{-3}; b) Pollen_200, defined as the number of days with pollen concentrations ≥200 pollen grains m^{-3}; c) Pollen_400, defined as the number of days with pollen concentrations ≥400 pollen grains m^{-3}; d) Pollen_600, defined as the number of days olive pollen concentrations ≥600 pollen grains m^{-3}; e) Pollen_800, defined as the number of days with pollen concentrations ≥800 pollen grains m^{-3}.

The meteorological variables considered in this study were all related to the months between the autumn of the previous year to late spring of the flowering year in order to do not delay the statistical modelization till the end of summer or autumn prior to the harvest. These variables were arranged as three-monthly (i.e., seasonal) as follows: October, November, December of the previous year (OND t-1); January, February, March (JFM) and April, May, June (AMJ) of the flowering year (t). These provided the mean maximum temperature (Tmax, °C), the mean minimum temperature (Tmin, °C) and the cumulative precipitation (Pacp, mm), being meteorological parameters commonly used as independent variables in the elaboration of olive yield forecasting models across the Mediterranean region (Aguilera and Ruiz-Valenzuela, 2014; Oteros et al., 2014). Meteorological data were provided by the University of Jaen weather station, which is over 200 m from the trap position.

2.2.2. Statistical methods

The forecasting models were constructed using partial least-squares regression, taking the annual olive yield as the dependent variable and the aerobiological and meteorological parameters as the independent variables. The modelling was based on linear transformation of the original descriptors to a small number of orthogonal factors (latent variables), to maximize the covariance between the descriptors and the dependent variable; this procedure provides the optimal linear model in terms of the forecasting. In the present study, each latent variable represented a key factor for the olive yield.

The annual olive yield data (tonnes of olive fruit) were provided by the Andalusian *Consejería de Agricultura, Pesca y Desarrollo Rural*.

Four regression models were built: two of them were regression models where the new aerobiological variables proposed in this study (Pollen_200 to Pollen_800), with or without the combination to the meteorological variables, were tested and used as independent variables, and two regression models whose elaboration was based in biometeorological forecasting models developed previously in the study area, where the SPIn as aerobiological parameter and different meteorological variables were used (Aguilera and Ruiz-Valenzuela, 2014).

The models were validated following a full cross-validation method, which is a statistical method for the evaluation and comparison of learning algorithms by dividing the data into two groups: one dataset was used to train the model and the other was used to validate the model (Refaeilzadeh et al., 2009). The advantage of using this validation method is that there is no need to exclude any year for the construction of the statistical models. The Unscrambler 9.7 software was used.

3. Results

The most relevant data of the five aerobiological variables and the olive fruit production in the study area during the period 1994–2016 are shown in Table 1. The mean number of days with pollen concentrations ≥200 pollen grains m^{-3} in the study area is of 35 (±7) days, a value considerably higher compared with the mean number of days with pollen concentrations ≥800 pollen grains m^{-3} (18 ± 6 days). The SPIn shows the highest interannual variability along the study period (cv. 49%), followed by olive fruit production (cv. 42%), and Pollen_400 (cv. 31%).

The statistical parameters of the four olive yield forecasting regression models are given in Table 2. The aerobiological parameters proposed in this study as possible new predictive indicators (Pollen_200 to Pollen_800) were tested in combination to the meteorological variables to the construction of the regression model A, while model B was similarly elaborated to above but considering the SPIn as aerobiological parameter. Models C and D were built using only aerobiological

Table 2
Summary of the partial least-squares regression parameters.

Model	Observed production (tonnes)	Predicted production (tonnes)	Determination coefficients		Root mean squared errors	
	Mean ± SD	Mean ± SD	Model R^2	Full cross validation Q^2	*Internal*	*External*
A	2,028,178 ± 844,098	1,964,652 ± 766,004	0.89	0.86	336,956	387,937
B	2,028,178 ± 844,098	1,951,668 ± 708,884	0.75	0.67	466,321	546,567
C	2,028,178 ± 844,098	1,952,773 ± 546,805	0.62	0.59	521,207	558,101
D	2,028,178 ± 844,098	1,920,476 ± 541,000	0.47	0.43	585,337	642,164

A: Pollen_400-meteo-based-model; B: SPIn-meteo-based-model; C: Pollen_400-based model; D: SPIn-based-model; *SD*, standard deviation.

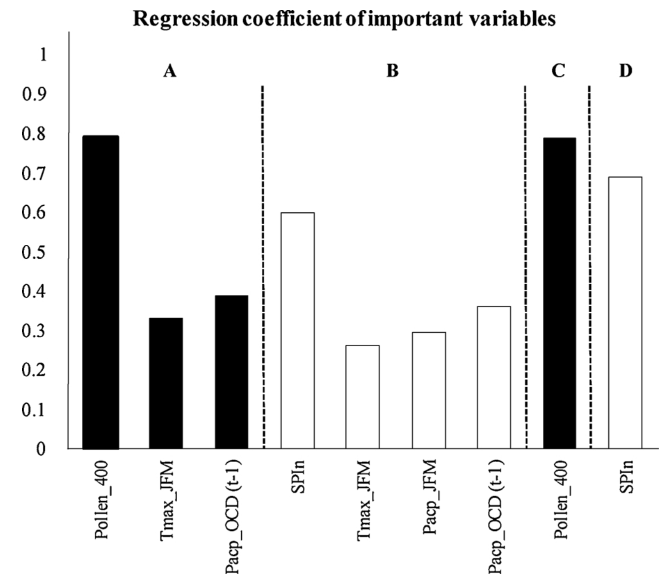

Fig. 2. Regression coefficient of the important variables included in the partial least-squares regression models. *Pollen_400*, defined as the number of days with pollen concentrations ≥400 pollen grains m^{-3}; *Tmax_JFM*, mean maximum temperature from January to March (°C); *Pacp_OND (t-1)*, cumulative precipitation from October to December of the previous year (mm); *Pacp_JFM*, cumulative precipitation from January to March (mm); *SPIn*, Seasonal Pollen Integral (pollen*day m^{-3}); A: Pollen_400-meteo-based-model; B: SPIn-meteo-based-model; C: Pollen_400-based model; D: SPIn-based-model.

parameters as predictive variables (Pollen_200 to Pollen_800 and SPIn respectively), obtaining the here called pollen-emission-based models.

The highest determination coefficient was obtained for the model A ($R^2 = 0.89$). Pollen_400 was the more important aerobiological predictive variable involved in the regression output to forecast the fruit production, showing a high and positive regression coefficient, while mean maximum temperature from January to March and the cumulative precipitation from October to December of the previous year were particularly relevant in this model (Fig. 2). These meteorological variables showed high and positive influence on the olive fruit production. The variation explained by the model B was lower than the previous one by 14%, although the determination coefficient can be considered high ($R^2 = 0.75$). Similar meteorological variables were included in this model, adding the cumulative precipitation from January to March, all of them with positive effects on crop production. In general, good results were obtained with the pollen-emission-based models, especially in the model C where Pollen_400 alone explained 62% of the variation of the annual yield ($R^2 = 0.62$) as opposed to SPIn, that explained 47% of the variability shown by the dependent variable ($R^2 = 0.47$). The regression models offer acceptable predictions given that the coefficients determined for the full cross-validation (Q^2) were all very close to the determination coefficients obtained in each model, reaching the maximum Q^2 value of 0.86 for the model A.

The observed and predicted values of yearly olive yields obtained by the four regression models that were validated using the full cross-validation method are reported in Fig. 3. The deviation between observed and predicted fruit production (absolute value) ranged from 0.2% to 41% using the model A (mean value 15%), between 6% to 56% by mean the model B (mean value 22%), between 2% to 90% using the model C (mean value 27%) and between 4% to 93% using the model D (mean value 39%). The efficiency of the models A and B is clearly higher than the others models mainly due to the accuracy of the estimations obtained. In these cases, almost all of the residuals fall within ± 400,000 tonnes of waste value for the model A and they ranged from -500,000 to +400,000 tonnes using the model B.

The relationships between the aerobiological parameters included in the models and olive fruit production were tested by simple linear regression (Fig. 4). A significant and strongly positive relationship was found between the SPIn and Pollen_400, with a R^2 of 0.74 ($p < 0.05$) (Fig. 4A). Although this statistical relationship may seem obvious, it helps us to verify that the aerobiological parameter that was revealed by the regression output as the more important for olive fruit production implicitly represents the other aerobiological variable used in the models. In the same way, a significant although weaker relationship regarding the previous one was found between the olive fruit production and Pollen_400, with a R^2 of 0.66 ($p < 0.05$) (Fig. 4B).

4. Discussion

Olive crop models have proved to be useful tools in increasing understanding of the mechanisms involved in crop system behaviour. Some biological parameters as pollen data represent a synthesis of the whole flowering period in a regional olive growing area, being in consequence an interest objective parameter to be used as a variable in forecasting the coming harvest. Research findings point to a close correlation between airborne pollen counts and fruit production in a number of wind-pollinated plants, being particularly marked in the olive (Aguilera and Ruiz-Valenzuela, 2014; Ben-Dhiab et al., 2017; Galán et al., 2008; Oteros et al., 2014; Ribeiro et al., 2008). Seasonal Pollen Integral is the aerobiological parameter usually used as predictive variable in the elaboration of olive yield forecasting models in these Mediterranean areas. However, increasing trends detected in both pollen intensity and duration of the pollen season of olive during the last two decades create the need to constant revise the forecasting models (Ruiz-Valenzuela and Aguilera, 2018).

In this study, the number of days with pollen concentrations ≥400 pollen grains m^{-3} was revealed as the aerobiological variable most influencing the final olive crop in the province of Jaen, being included in the forecasting model with the highest determination coefficient value. Airborne pollen count, besides expressing the number of male gametes potentially useful for the reproduction process, provides indirect information on the number of available flowers, and consequently of ovaries that could become fruits (Orlandi et al., 2010; Reale et al., 2006). The variable Pollen_400 combines alone airborne pollen intensity and time of presence in the air, providing better prediction results with respect the SPIn. Given that olive tree is an anemophilous species that produce a remarkable excess of pollen with respect to that needed for fertilization (Barranco et al., 2008; Cuevas et al., 2009), it would not be surprising that a variable that synthesizes this information is appropriate for making predictions of the final harvest. Moreover, with this new aerobiological indicator pollen transport from other regions at the begin and end of the main pollen season or pollen resuspension at the end of this period, that do not contribute to the pollination process, are no longer accounted. The findings shown in this study suggest that, for a successful fertilization process and consequently higher fruit production in the olive tree, it may be more convenient to have a prolonged pollination period with airborne pollen concentrations not lower than 400 pollen grains m^{-3} than knowing the total pollen amount during the whole pollen season. These airborne pollen concentrations are reached and commonly surpassed in the main intensive olive growing areas located in the Mediterranean region (Aguilera and Ruiz-Valenzuela, 2014; Galán et al., 2008; Oteros et al., 2014).

Although the use of aerobiological variables in the crop yield forecasting give to statistical models scientifically acceptable descriptions of processes involved in the reproductive cycle of the plant, predictions improve by incorporating weather-related factors. The relationship between yield and weather conditions becomes evident at the critical time of flower growth and ripening, as has been previously reported for olive growing areas across the Mediterranean region (Ben-Dhiab et al., 2017; Fornaciari et al., 2005; Galán et al., 2008; González-Minero et al., 1998; Orlandi et al., 2010, 2017; Oteros et al., 2014; Ribeiro et al.,

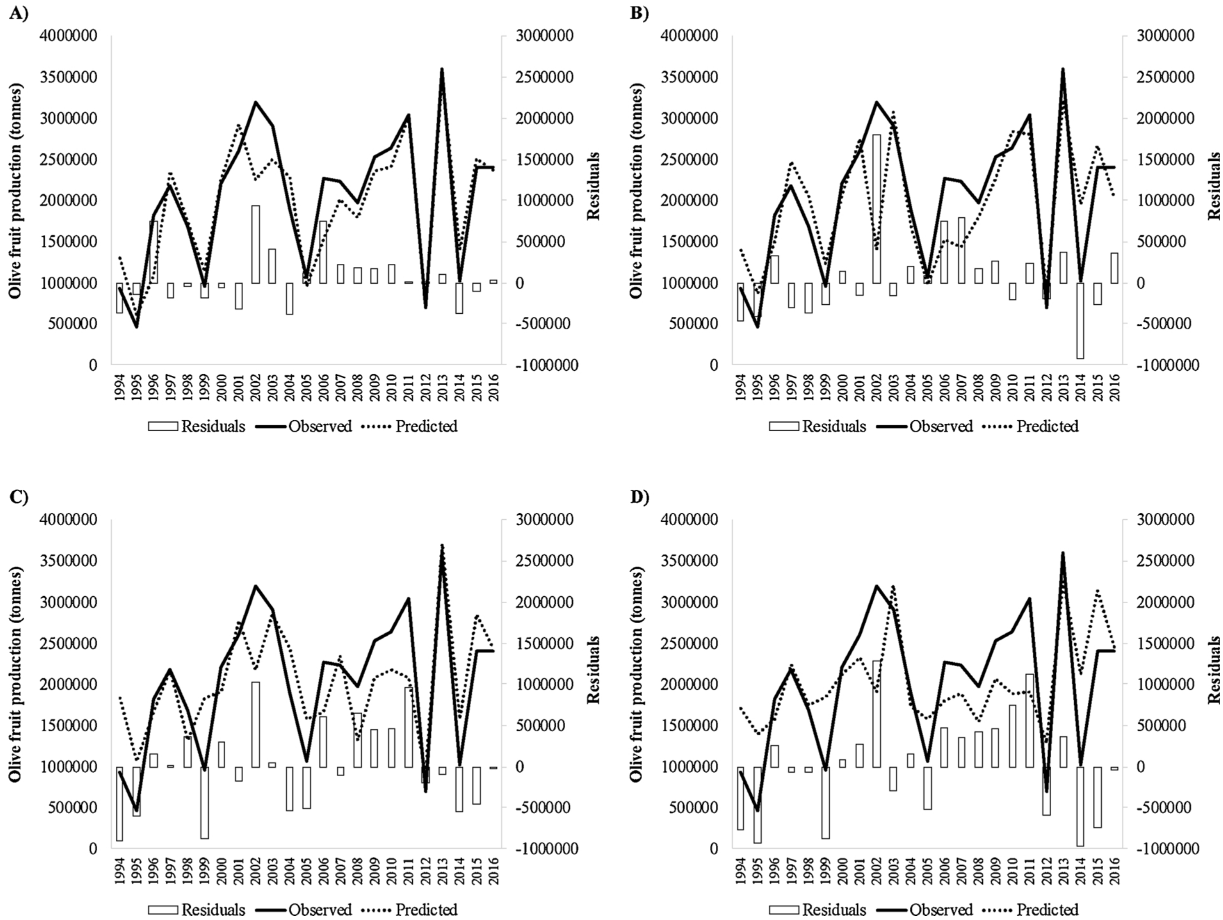

Fig. 3. Observed and predicted values of the olive fruit productions (tonnes) according to the different partial least-squares regression models. A: Pollen_400-meteo-based-model; B: SPIn-meteo-based-model; C: Pollen_400-based model; D: SPIn-based-model.

2007). The results obtained here confirm that variables as the maximum temperatures or the cumulative precipitation during the pre-flowering months are of particular importance in crop production.

Temperature is an important factor affecting fruit production, since it is closely related to the biological reproductive cycle of the olive tree, especially with the flowering period (Aguilera and Ruiz-Valenzuela, 2014; Aguilera et al., 2015a, 2015b; Bonofiglio et al., 2009; Galán et al., 2008). Mean maximum temperature from January to March was a variable included in two of the regression models, showing a positive effect on the final fruit production. In similar climate areas, maximum temperatures previous to budbreak or from this to the start of flowering contributed positively to the forecasting models (Ben-Dhiab et al., 2017; García-Mozo et al., 2008; Oteros et al., 2014). During this period, reproductive structures are fully engaged in intensive morphological and histological development, extension and microsporogenesis, so, these require energy (Barranco et al., 2008). Others authors note a similar positive relationship between maximum temperature prior to flowering and fruit production, attributed to these temperatures affect photosynthetic capacity (Koubouris et al., 2009).

The precipitation is another important factor capable of providing an explanation to the existing fluctuations in fruit production. The rain recorded during the previous autumn and pre-flowering months has a powerful positive effect on final crop production, being a weather factor included in both bio-meteorological models. Rainfall-related variables, particularly during these months, determine the availability of water for the development of floral buds and the various flowering phenophases during spring. According to Rallo (1994), the water stress in the months preceding flowering reduces the number of flowers in the olive tree. This fact could result in a lower pollen release and in a reduced availability of ovaries, potential fruits. Several works on olive harvest prediction made in central and south Spain (Candau-Fernández-Mensaque et al., 1998; Galán et al., 2008; García-Mozo et al., 2008; Oteros et al., 2013) and other countries such as Italy (Orlandi et al., 2010), Tunisia (Ben-Dhiab et al., 2017) and Portugal (Ribeiro et al., 2008) agree on this fact. These studies highlighted the particular importance of rainfall and water availability during pre-flowering and flowering in Mediterranean climate areas, where there are frequent periods of drought.

The merit of a forecasting model is based on several factors, principally its originality and contribution to the science of systems harvest (Sinclair and Seligman, 2000). Under these criteria, model A can be proposed as an optimal model to forecast the fruit produced by the olive groves in southern Spain. On the one hand, this model represents an improvement of regression forecasting models previously reported for Jaen, the largest extension of olive groves in the world (Aguilera and Ruiz-Valenzuela, 2014; International Olive Council, 2018). Model A gives early and effective olive crop forecasting by using only three independent variables which can be easily obtained before July, while preceding local models with similar determination coefficients involved until six predictive variables in the regression output. Moreover, the accuracy of the fruit predictions obtained by mean this model is better than the previous one (Aguilera and Ruiz-Valenzuela, 2014). On the other hand, a new and unusual use of the aerobiological data has been here reported and proved to be useful for olive crop forecasting. This variable can not only be used as a good bioindicator of the final harvest, but also incorporates to the models the phenological variability associated with changes in the local weather. Frequently, local models developed in olive growing areas through the Mediterranean region

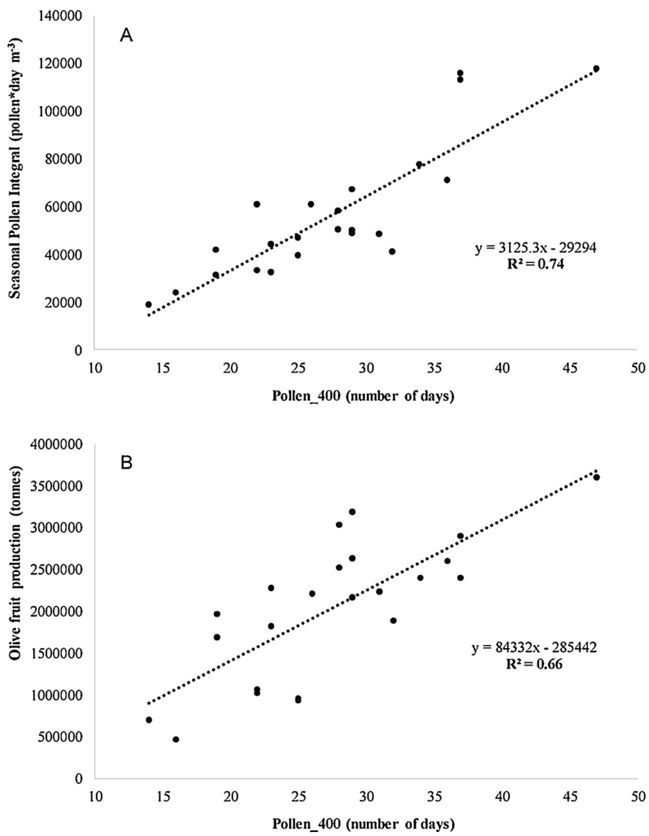

Fig. 4. Linear fit (dotted line) of the regression analysis between A; the Seasonal Pollen Integral (pollen*day m^{-3}) and Pollen_400 (number of days with pollen concentrations ≥400 pollen grains m^{-3}) and B; Olive fruit production (tonnes) and Pollen_400 (number of days with pollen concentrations ≥400 pollen grains m^{-3})a.

involved a higher number of independent variables, some of them obtained from the end of flowering to the fruit maturation, thus delaying olive crop predictions (Ben-Diab et al., 2017; García-Mozo et al., 2008; Oteros et al., 2014). According to our preceding study, the use of parameters related to the summer season and with months before harvest did not substantially improve the degree of explanation of the forecasting models in the study area, so, these were not used in the elaboration of the regression models.

The approach shown in this study should not be restricted to a specific circumstance. The models obtained, especially the model A, readily could be applied to any potential new situation and therefore to be extensible to other similar olive growing areas across the Mediterranean region. Finally, and given the economic importance of the olive tree cultivation in south Spain, early and effective harvest-forecasting would provide the farmers and regional agricultural institutions information of great value which could be used in agronomic and economic planning strategies, such as the management of cropping systems and global commercial distribution.

5. Conclusions

An improved partial least-squares regression model is proposed as more effective for forecasting the fruit produced by the olive trees in southern Spain. Pollen_400, a newfangled predictive variable that combines airborne pollen intensity and time of presence in the air, has been proved useful to accurately predict the olive harvest in this area. Weather-related variables such as the cumulative precipitation or the mean maximum temperature during the pre-flowering months are factors of particular importance on crop production. The new model proposed provides early and optimal olive crop forecasting by using independent variables which can be easily and prematurely obtained, also incorporating to the model the phenological variability associated with changes in the local weather.

Acknowledgements

The authors are grateful to the University of Jaen for providing the meteorological data and to the Andalusian *Consejería de Agricultura, Pesca y Desarrollo Rural* for providing the olive yield data. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Aguilera, F., Ruiz-Valenzuela, L., 2012. Microclimatic-induced fluctuations in the flower and pollen production rate of olive trees (*Olea europaea* L.). Grana 51, 228–239.
Aguilera, F., Ruiz-Valenzuela, L., 2014. Forecasting olive crop yields based on long-term aerobiological data series and bioclimatic conditions for the south Iberian Peninsula. Span. J. Agric. Res. 12, 215–224.
Aguilera, F., Orlandi, F., Ruiz-Valenzuela, L., Msallem, M., Fornaciari, M., 2015a. Analysis and interpretation of long temporal trends in cumulative temperatures and olive reproductive features using a seasonal trend decomposition procedure. Agric. For. Meteorol. 203, 208–216.
Aguilera, F., Fornaciari, M., Ruiz-Valenzuela, L., Galán, C., Msallem, M., Ben-Dhiab, A., et al., 2015b. Phenological models to predict the main flowering phases of olive (*Olea europaea* L.) along a latitudinal and longitudinal gradient across the Mediterranean region. Int. J. Biometeorol. 59, 629–641.
Araque, E., Gallego, V.J., Sánchez, J.D., 2002. El olivar regado en la provincia de Jaén. Investigaciones Geográficas 28, 5–32 *In Spanish*.
Barranco, D., Fernández-Escobar, R., Rallo, L. (Eds.), 2008. El Cultivo del olivo, 6th Ed. Junta de Andalucía y Ediciones Mundi-Prensa, Sevilla, Spain, pp. 846 In Spanish.
Bastiaanssen, W.G.M., Ali, S., 2003. A new crop yield forecasting model based on satellite measurements applied across the Indus Basin. Pakistan. Agric. Ecosyst. Environ. 94, 321–340.
Baugnent, E., 1991. Contribution à l'étude des prévisions de récole viticole à partir de l'analyse du contenu pollinique de l'atmosphére. Mémoire de fin d'études. Ecole nationale d'ingénieurs des travaux agricoles. Bordeaux, Francia.
Ben-Dhiab, A., Ben-Mimoun, M., Oteros, J., García Mozo, H., Domínguez-Vílches, E., Galán, C., Abichou, M., Msallem, M., 2017. Modeling olive-crop forecasting in Tunisia. Theor. Appl. Climatol. 128, 541–549.
Bonofiglio, T., Orlandi, F., Sgromo, C., Romano, B., Fornaciari, M., 2009. Evidences of olive pollination date variations in relation to spring temperature trends. Aerobiologia 25, 227–237.
Candau-Fernández-Mensaque, P., González-Minero, F.J., Morales, J., Tomás, C., 1998. Forecasting olive (*Olea europaea*) crop production by monitoring airborne pollen. Aerobiologia 14, 185–190.
Consejería de Agricultura, Pesca y Desarrollo Rural, 2018. http://www.juntadeandalucia.es/organismos/agriculturapescaydesarrollorural/consejeria/sobre-consejeria/estadisticas/paginas/agrarias-superficies-producciones.html. (Accessed 29 June 2018). In Spanish.
Cuevas, J., Pinillos, V., Polito, V.S., 2009. Effective pollination period for 'Manzanillo' and 'Picual' olive trees. J. Hortic. Sci. Biotechnol. 84, 370–374.
Cunha, M., Abreu, I., Pinto, P., Castro, R., 2003. Airborne pollen samples for early-season estimates of wine production in a Mediterranean climate of Northern Portugal. Am. J. Enol. Viticult. 54, 189–194.
De Boissezon, H., 1995. Rapid estimates of acreage and potential yield in the European Union. Proceedings of the Workshop for the Central and Eastern Europe on: Agrometeorological Models: Theory and Applications in the MARS Project.
Fei, T., Wenbin, W., Dandan, L., Zhongxin, C., Qing, H., Tian, X., 2012. Yield estimation of winter wheat in North China Plain by using crop growth monitoring system (CGMS). Agro-Geoinformatics (Agro-Geoinformatics). First International Conference on 1–4.
Fornaciari, M., Pieroni, L., Orlandi, F., Romano, B., 2002. A new approach to consider the pollen variable in forecasting yield models. Econ. Bot. 56, 66–72.
Fornaciari, M., Orlandi, F., Romano, B., 2005. Yield forecasting for olive trees: a new approach in a historical series (Umbria, Central Italy). Agron. J. 97, 1537–1542.
Galán, C., García-Mozo, H., Vázquez, L., Ruiz-Valenzuela, L., Díaz de la Guardia, C., Domínguez, E., 2008. Modeling olive crop yield in Andalusia. Spain. Agron. J. 100, 98–104.
Galán, C., Smith, M., Thibaudon, M., Frenguelli, G., Oteros, J., Gehrig, R., et al., 2014. Pollen monitoring: minimum requirements and reproducibility of analysis. Aerobiologia 30, 385–395.
Galán, C., Alcázar, P., Oteros, J., García-Mozo, H., Aira, M.J., Belmonte, J., et al., 2016. Airborne pollen trends in the Iberian Peninsula. Sci. Total Environ. 550, 53–59.
Galán, C., Ariatti, A., Bonini, M., Clot, B., Crouzy, B., Dahl, A., et al., 2017. Recommended terminology for aerobiological studies. Aerobiologia 33, 293–295.
García-Mozo, H., Orlandi, F., Galán, C., Fornaciari, M., Romano, B., Ruiz-Valenzuela, L., Díaz de la Guardia, C., Trigo, M.M., Chuine, I., 2008. Olive flowering phenology variation between different cultivars in Spain and Italy: modelling analysis. Theor. Appl. Climatol. 95, 385–395.
García-Mozo, H., Domínguez-Vílchez, E., Galán, C., 2012. A model to account for variations in holm-oak (*Quercus ilex* subsp. ballota) acorn production in southern Spain.

Ann. Agric. Environ. Med. 19, 411–416.
González-Minero, F.J., Candau, P., Morales, J., Tomás, C., 1998. Forecast olive crop production based on ten consecutive years of monitoring airborne pollen in Andalucía (south Spain). Agric. Ecosyst. Environ. 69, 201–215.
Hirst, J.M., 1952. An automatic volumetric spore trap. Ann. Appl. Biol. 39, 257–265.
International Olive Council, 2018. http://www.internationaloliveoil.org. (Accessed 27 June 2018).
Koubouris, G.C., Metzidakis, I.T., Vasilakakis, M.D., 2009. Impact of temperature on olive (*Olea europaea* L.) pollen performance in relation to relative humidity and genotype. Environ. Exp. Bot. 67, 209–214.
Lletjos, R., Bartroli, R., Esteban, A., Riera, S., 1993. Forecasting hazelnut (*Corylus avellana* L.) crop production based on monitoring airborne pollen concentration. Coll, C.R. (Ed.), IV Int. Symp. on Fruit, Nut and Vegetable Production Engineering.
Loumou, A., Giourga, C., 2003. Olive groves: the life and identity of the Mediterranean. Agric. Hum. Values 20, 87–95.
Miller, A.J., 1990. Subset Selection in Regression. Marcel Dekker, New York.
Orlandi, F., Sgromo, C., Bonofiglio, T., Ruga, L., Romano, B., Fornaciari, M., 2010. Yield modelling in a Mediterranean species utilizing cause-effect relationships between temperature forcing and biological processes. Sci. Hortic. 123, 412–417.
Orlandi, F., Aguilera, F., Galán, C., Msallem, M., Fornaciari, M., 2017. Olive yield forecasts and oil price trends in Mediterranean areas: a comprehensive analysis of the last two decades. Exp. Agric. 53, 71–83.
Oteros, J., García-Mozo, H., Hervás-Martínez, C., Galán, C., 2013. Year clustering analysis for modelling olive flowering phenology. Int. J. Biometeorol. 57, 307–316.
Oteros, J., Orlandi, F., García-Mozo, H., Aguilera, F., Ben-Dhiab, A., Bonofiglio, T., et al., 2014. Better prediction of Mediterranean olive production using pollen-based models. Agron. Sustain. Dev. 34, 685–694.
Palm, R., 1995. Regression Methods Including the Eurostat Agromet Model and Time Trends. Joint Research Centre of the E.U Publication EUR 16008 EN. Office for Official Publ. of the E.U., Luxembourg.
Rallo, L., 1994. Fructificación y producción en olivo. Agricultura: revista agropecuaria 63/746. pp. 725–728 In Spanish.
Reale, L., Sgromo, C., Bonofiglio, T., Orlandi, F., Fornaciari, M., Ferranti, F., Romano, B., 2006. Reproductive biology of Olive (*Olea europaea* L.) DOP Umbria cultivars. Sex. Plant Reprod. 19, 151–161.
Refaeilzadeh, P., Tang, L., Liu, H., 2009. Cross-validation. In: Liu, L., Özsu, M.T. (Eds.), Encyclopedia of database systems. Springer, pp. 532–538.
Ribeiro, H., Cunha, M., Abreu, I., 2007. Improving early-season estimates of olive production using airborne pollen multi-sampling sites. Aerobiologia 23, 71–78.
Ribeiro, H., Cunha, M., Abreu, I., 2008. Quantitative forecasting of olive yield in Northern Portugal using a bioclimatic model. Aerobiologia 24, 141–150.
Ribeiro, H., Abreu, I., Cunha, M., 2017. Olive crop-yield forecasting based on airborne pollen in a region where the olive groves acreage and crop system changed drastically. Aerobiologia 33, 473–480.
Ruiz-Valenzuela, L., Aguilera, F., 2018. Trends in airborne pollen and pollen-season-related features of anemophilous species in Jaen (south Spain): a 23-year perspective. Atmos. Environ. https://doi.org/10.1016/j.atmosenv.2018.03.012.
Sharman, M., De Boisezzon, H., Gonzales, G., Pous, B., 1992. Rapid estimates of acreages and potential yield at a European scale. Proceedings of the 43rd Congress of the International Astronautical Federation.
Sinclair, T.R., Seligman, N., 2000. Criteria for publishing papers on crop modelling. Field Crop Res. 65, 165–172.
Spanish Statistical Office, 2017. http://www.ine.es/dyngs/INEbase/es/. (Accessed May 2017).
Tormo-Molina, R., Gonzalo-Garijo, M., Silva-Palacios, I., Muñoz-Rodríguez, A., 2010. General trends in airborne pollen production and pollination periods at a Mediterranean site (Badajoz, southwest Spain). J. Investig. Allergol. Clin. Immunol. 20, 567–574.
Villalobos, F.J., Testi, L., Hidalgo, J., Pastor, M., Orgaz, F., 2006. Modelling potential growth and yield of olive (*Olea europaea* L.) canopies. Eur. J. Agron. 24, 296–303.