Forecasting olive (*Olea europaea*) crop yield based on pollen emission

Carmen Galán*, Luis Vázquez, Herminia García-Mozo, Eugenio Domínguez

*Dpto. Biología Vegetal, Colonia San José Casa No. 4, Campus de Rabanales, Universidad de Córdoba, Córdoba 14071, Spain*

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**Abstract**

Reliable crop volume estimations are an increasing necessity to allow optimised and effective agronomic management. In this paper, a methodology to evaluate future olive crop yield several months in advance is presented. Olive tree phenology, airborne pollen concentrations, meteorological data and fruit production data were analysed in the province of Córdoba (Andalusia, Spain) over a period of 20 years (1982–2002). Data were integrated to obtain models for predicting fruit production.

In this study, annual *Olea* pollen emission is shown to be a reliable bio-indicator to forecast olive fruit production up to 8 months in advance. Hirst volumetric pollen traps were found to be an accurate tool in olive crop yield forecasting. May rainfall was the most important meteorological parameter affecting final fruit production. Three statistical models, with different elapsed time between crop estimation and harvest, were developed: 8, 4 and 2 months. All showed high determination coefficients (73–98%) with a significance of 99%. The models revealed no significant differences between expected and actual data in the 2001/2002 olive harvest (not included in the model). Comparisons with other estimations from the regional government indicated that the meteo-aerobiological methodology showed higher anticipation and also a higher level of coincidence between expected and actual data. In addition to the positive results from this study, the scientific basis of the statistical performance provides accuracy and objectivity to this forecasting methodology.

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1. **Introduction**

For thousands of years, *Olea europaea* L. has been one of the most extensive crops in the Mediterranean region. Fruits and oil are among the oldest and the most important products. Spain produces 33% of the world’s total olive oil output, the region of Andalusia accounting for 80% of the total Spanish production.

Advanced knowledge about annual crop production is highly desirable from both biological and economic point of view. Early and effective crop forecasting is essential for optimising both technical and human resources for harvesting and also for planning olive oil marketing and commercial distribution globally. This fact has great importance for the olive crop since it is one of the main targets of the European Union economic policy (Abassi, 2001).

Although aerobiological studies have been traditionally applied to allergy research (Domínguez et al., 1993; Florido et al., 1999), today their usefulness is being shown for crop forecasting. Annual pollen

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*Corresponding author. Tel.: +34-957-218-719; fax: +34-957-218-598. E-mail address: bv1gasoc@uco.es (C. Galán).
emission is a measure of the quality of the season and can thus be used as a bio-indicator of fruit production. Similarly, meteorological parameter influence on fruit development must be taken into account for olive crop yield forecasting, especially in changeable climatic conditions such as those of the Mediterranean region.

In the province of Córdoba (Andalusia, Spain) the most arable land is used for olives. The olive tree flowers in Córdoba during the spring (April–June). Olive pollen is one of the most important airborne pollen types recorded in the Mediterranean region, particularly in Andalusia, due to the abundance of this crop in the area. The pollen season usually starts in the second half of April, although the date depends on temperatures over the preceding period. The tree requires an average of 210° heat units to flower, calculated as growing degree days, over a threshold temperature (Gala et al., 1998). Annual pollen emission is highly variable, and depends first on rainfall, particularly in March, and secondly on temperature (Galán et al., 2001b).

The olive harvest time takes place in winter, usually from November to February. Although a typical biannual pattern of alternate bearing has been described for olive, in the Andalusia region this alternation sometimes disappears due to water stress (Díaz de la Guardia et al., 2000). Warm temperatures and moderate rainfall in the period between pollination and fruit ripening favours fruit production (González-Minero et al., 1998). On the other hand, extreme meteorological phenomena such as autumn frosts, summer severe drought, heavy rainfall and hail can affect final fruit production.

This study aimed to build models for reliable olive crop forecasting in the Córdoba province (Andalusia, Spain) by using pollen emission data and meteorological parameters in the period following blooming. A previous study carried out by Fornaciari et al. (2000) indicated that the aerobiological database of the city of Córdoba was suitable. Three models were built for predicting crop production in advance of final harvest at three different times of the year: just after blooming (8 months in advance), just before the beginning of harvesting (4 months), and during harvesting (2 months). These forecasting models were validated with actual crop yield data from years not included in the models, and also compared with the estimated crop yield data produced by the Agriculture and Fisheries Department of the Andalusian Regional Government (AFDA), based on previous crop data and farmers’ visual estimations.

2. Materials and methods

2.1. Study area

The location of Córdoba province and the distribution of olive cultivation throughout the Andalusia region (southern Spain) is represented in Fig. 1 (SINAMBA data provided by the Andalusia Regional Government). Olive distribution is concentrated in the south-east of the province. The olive cultivation area in this province was about 345 317 ha in 2000 (Anuario Estadístico de Andalucía, 2002). Of this area, up to 342 005 ha were used for olive oil production. Córdoba is therefore the world’s second largest olive oil-producing province after Jaén. The climate is Mediterranean, with an annual average temperature of 17.6 °C and rainfall of 536 mm (Spanish National Institute of Meteorology, 2001).

2.2. Aerobiological methodology

Aerobiological data were collected over a 20-year (1982–2002) period using a volumetric Hirst spore-trap (Hirst, 1952), Lanzoni® VPPS 2000 model. The standard sampling procedures proposed by the Spanish Aerobiology Network (REA) were employed (Domínguez et al., 1992; Galán, 1998). The volumetric trap was located on the roof of the Educational Sciences Faculty of Córdoba city, 15 m above ground level. The sampling trap has two parts: a lower fixed part and an upper mobile part with a winged portion that positions the trap slit opening into the wind. The trap absorbs a constant air-flow volume (10 l min⁻¹). Airborne solid particles stick to a drum with Melinex® adhesive tape situated over a clock. This clock allows distinction of particles from different periods. By knowing the volume of air that enters, the concentration of particles per cubic metre can be expressed hourly, daily, or weekly. Finally the adhesive tape was stained with fuchsine and pollen grains were analysed with the aid of a light microscope (400× magnification).
Fig. 1. Location of Córdoba province and olive production areas in Andalusia (SINAMBA).
Due to the physical characteristics of the olive pollen grain and to the climatic conditions of the area, the trap is capable of monitoring the olive groves distributed within a radius of 100 km surrounding the valley where the trap is located (Domínguez et al., 1993; Fornaciari et al., 2000).

2.3. Crop forecasting

The present paper uses the pollen index (PI) as a variable to forecast olive yield. PI is the sum of the daily pollen concentration in the air expressed as the daily average of pollen grains per cubic metre from the start of pollination to the maximum pollen concentration date (Fig. 2). The start of the olive pollen season was deemed to be the date on which 1 pollen grain m\(^{-3}\) was recorded and when subsequent days (at least 5 consecutive days) also showed one or more pollen grains per cubic metre (Galán et al., 2001a). Based on many years of experience in aerobiological studies of olive, the total annual pollen emitted is not directly important to fruit production estimation as each olive tree produces a large excess of pollen with respect to that needed for fertilisation (Pesson and Louveaux, 1984; Barranco et al., 1998). Moreover previous phenological surveys indicated that the PI should include only the pre-peak period of the total pollen season curve (Fig. 2) since the maximum peak in the curve occurred when the last olive grove of the province flowered, located on the slopes of the Sierra Subbética, on the southern border of the province (Fornaciari et al., 2000; Vázquez et al., 2002). On the other hand, the post-peak period corresponds to pollen coming from other locations and re-flotation.

A multiple regression analysis was applied to produce the forecast with olive fruit production as the dependent variable. Total olive fruit production data for Córdoba province was taken from official sources, i.e. the Statistical Data Yearbook published by the Andalusian Regional Government. PI and monthly meteorological data, including temperature and rainfall, over the period after flowering and before harvesting (May–December), were used as the independent variables. Meteorological data were supplied by the Spanish National Institute of Meteorology. A 20-year aerobiological and meteorological database (from 1982 to 2002) was used for the statistical analysis. However, year 2002 was not used for producing the models as it was used for the validation phase. STATISTICA PC for Windows 98 was used for this work.

To forecast the 2001/2002 production (not included in the model) three different forecasts were made at

![Fig. 2. Average daily pollen concentration (1982–2001). The arrow indicates the peak day in the curve.](image-url)
different periods of the year. Results were validated with the real olive crop yield data of the province of Córdoba and compared with the forecasts produced by the Agriculture and Fisheries Department of the Andalusian Regional Government (AFDA) for the same production. Real olive crop yield data from AFDA was not available before May each year. This institution now produces olive fruit production estimates at different times of the year. Estimations take into account differences in fruit production between current and previous years as well as industrial performance for the current season. To estimate these two parameters two different variables are needed: oil mill output figures for the previous year and farmer surveys. The estimations thus obtained should be considered as fairly subjective, and therefore not very accurate. Knowledge of total pollen emission into the atmosphere enables flowering to be quantified, and provides a more objective parameter to be used as a variable in forecasting the coming harvest.

3. Results

Fig. 3 shows the intra-annual variation of monthly temperature and rainfall. The Mediterranean characteristics of the climate in Córdoba are clearly evident, with scarce rainfall and highest temperatures in summer and rain and colder temperatures in the autumn. The wind pattern in the province is characterised by complex local behaviour due to topographical features (mountains and valleys) (Domínguez-Bascón, 2002). The main wind direction is south to north which favours the detection of pollen grains from the main olive-growing areas in the city (Table 1). Nevertheless previous studies on the influence of this parameter

![Graph showing monthly temperature and rainfall](https://example.com/graph.png)

**Fig. 3.** Twenty year average data for monthly mean temperature and monthly rainfall from May to December in the area of Córdoba.

<table>
<thead>
<tr>
<th>Month</th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
<th>November</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind direction (°)</td>
<td>210</td>
<td>200</td>
<td>230</td>
<td>200</td>
<td>250</td>
<td>230</td>
<td>230</td>
<td>230</td>
<td>230</td>
<td>210</td>
<td>220</td>
<td>210</td>
</tr>
<tr>
<td>Wind velocity (km/h)</td>
<td>80</td>
<td>78</td>
<td>83</td>
<td>83</td>
<td>93</td>
<td>63</td>
<td>65</td>
<td>59</td>
<td>76</td>
<td>74</td>
<td>96</td>
<td>126</td>
</tr>
</tbody>
</table>

Table 1
Average monthly wind direction and maximum velocity detected in the city of Córdoba during the period 1971–2000 (source: Spanish National Institute of Meteorology, 2001)
have revealed that wind direction and velocity are not key factors in daily olive pollen emission (Domínguez et al., 1993).

Fig. 4 illustrates the link between fruit production of the province and the PI. Pollen emission displays an alternating pattern from year to year: any year with high flower production is followed by a decrease in flower production. However, this pattern was disrupted during 1993–1995 due to a severe water stress period. A close link between rainfall and pollen emission can be observed probably due to the special characteristics of the Mediterranean climate. The high degree of coincidence between the two patterns is noticeable. The average fruit production in Córdoba in the period studied was 650 963.4 million t. Annual olive crop production also shows an alternating pattern for most of the study years. In later years, the crop area increased, probably due to European Union agricultural policy which has favoured olives.

The use of pollen emission and monthly meteorological data from 1982 to 2000 as predictive variables has enabled us to produce a forecast up to 8 months prior to the end of harvesting. Table 2 shows predictive formulae used to forecast fruit production.

![Fig. 4. Annual fruit production (Produc.) versus PI.](image)

Table 2
Forecast models and forecast date (date in which forecasts models were made)*

<table>
<thead>
<tr>
<th>Forecast date</th>
<th>Forecast model</th>
<th>Adjusted $R^2$</th>
<th>$P$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 2001</td>
<td>$y = -30.501 + 3026(RfMy) + 28(PI) + 89.820(MnTMy) - 184.848(MnTJn) + 66.879(MxTJn)$</td>
<td>0.73</td>
<td>&lt;0.00027</td>
</tr>
<tr>
<td>November 2001</td>
<td>$y = -120.860 + 6627(RfMy) + 53(PI) + 1333.073(MnTO) + 1532(RfO) + 7808(RfJl) - 7216(MxTO) - 83.753(MnTJl)$</td>
<td>0.83</td>
<td>&lt;0.00011</td>
</tr>
<tr>
<td>January 2002</td>
<td>$y = -2.406.646 + 7381(RfMy) + 44(PI) + 75.532(MnTO) + 2693(RfO) + 5938(RfJl) - 5993(MxTO) - 79.590(MxTD) + 2852(RfJn) + 47.365(MxTJn) - 2582(RfS) + 626(RfN) + 34.507(MxTN) + 22.724(MnS)$</td>
<td>0.98</td>
<td>&lt;0.00013</td>
</tr>
</tbody>
</table>

* PI: pollen index; Rf: rainfall; MnT: minimum temperature; MxT: maximum temperature; AT: average temperature; My: May; Jn: June; Jl: July; A: August; S: September; O: October; N: November; D: December.
Three forecasts were produced: one in July of the previous year, taking into account the PI and meteorological data from spring; another in November of the previous year, which reflects the PI and meteorological data from May to October; and a third in January of the current harvest year, which reflects the PI and meteorological data from May to December.

All the variables considered are listed in Table 2. In all the models, the main influencing variables were PI and the rainfall registered in May (Table 2). Both entered into all proposed equations as positive. Other important parameters to be taken into account were: air minimum and maximum temperature from June (entering into all equations) with minimum temperature affecting crop development negatively and higher maximum temperature favouring fruit development; temperature during October which exerted an opposite effect with maximum temperature negatively influencing crop development and minimum temperature being positive for crop production, as can be seen in both November and January equations. The regression coefficients of the variables are significant (probability level of 99 %) with $R^2$ coefficients of 0.73, 0.83 and 0.98, for the equations of July, November and January, respectively (Table 2).

Table 3 shows the validation of the models for the olive harvest of 2001/2002, when total production data was not available until May 2002. The forecasts produced by the AFDA for 2001/2002 are also given in Table 3. Apart from the higher anticipation of our methodology, the meteo-aerobiological forecasts were more precise. Nevertheless, the most accurate forecasting model was the “November meteo-aerobiological model”, 4 months before the end of harvesting.

4. Discussion and conclusions

Airborne pollen monitoring has been shown to be a useful tool in olive crop yield prediction. A pioneering method developed by Cour (1974) has been traditionally applied to forecast fruit production in various crops of economical interest, and especially in O. europaea (Candau et al., 1998; González-Minero et al., 1998). The main disadvantage of this volume-gravimetric method is the long and complex analysis process which involves management errors which are difficult to detect and solve (Esteban et al., 1996). However, the methodology proposed by Hirst (1952) has been used as an alternative tool in this type of survey with optimal results for the olive crop (Fornaciari and Romano, 1995; Moriondo et al., 2001; Fornaciari et al., 2002). This methodology requires an initial higher invest than Cour’s, and may not be representative in the case of low pollen concentrations, although its characteristics make it reliable for crop yield forecasting in anemophilous cultures that release high volumes of pollen grains such as olive (Riera, 1995). On the other hand, it has many other advantages. The airborne pollen concentration values are obtained from time-continuous sampling, which allows production of daily and even hourly pollen emission data. The management process does not require chemical analysis which reduces sources of error (Esteban et al., 1996).

It is impossible to determine exactly the area of influence of an aerobiological sampler. It depends on several factors such as pollen type, topography, vegetation distribution and meteorological factors (Levizzani, 1998). However, for olive pollen previous

<table>
<thead>
<tr>
<th>AFDA</th>
<th>Expected data (Tm)</th>
<th>Exp – Act$^a$ (Tm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>December 2001</td>
<td>1064000</td>
<td>−328388</td>
</tr>
<tr>
<td>January 2002</td>
<td>1051000</td>
<td>−341388</td>
</tr>
<tr>
<td>March 2002</td>
<td>1217000</td>
<td>−175388</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Aerobiological methodology</th>
<th>Expected data (Tm)</th>
<th>Exp – Act$^b$ (Tm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 2001</td>
<td>1057306</td>
<td>−335053</td>
</tr>
<tr>
<td>November 2001</td>
<td>1390014</td>
<td>−2345</td>
</tr>
<tr>
<td>January 2002</td>
<td>1253724</td>
<td>−138635</td>
</tr>
</tbody>
</table>

$^a$ Mean absolute value: 281 721.  
$^b$ Mean absolute value: 176 010.
phenology studies have indicated that a sampler placed in Córdoba city detects pollen grains from olive groves located up to 100 km away (Domínguez et al., 1993; Fornaciari et al., 2000). The high degree of coincidence between annual province olive yield data and the olive PI recorded by the Córdoba city sampler has allowed us to confirm that the PI is a reliable bio-indicator of province olive crop production. Moreover, pollen from the olive groves situated in Jaen and Granada provinces (Fig. 1), which is usually emitted later in the season, are scarcely represented in the Córdoba olive pollen data (Florido et al., 1999; Vázquez et al., 2002).

The total pollen emitted into the atmosphere can be used as a representative index, of the floral phenology from different cultivars and areas; by this means, airborne pollen concentration due to re-flotation can be excluded. The PI is determined by the physiological characteristics of the tree and influenced by meteorological parameters prior to the flowering period (rainfall, and to a lesser extent temperature) in the Mediterranean region (Galán et al., 2001b). Nevertheless, meteorological parameters during and after the flowering period have the most influence on final olive crop production, as was suggested by Moriondo et al. (2001), and Fornaciari et al. (2002). The main meteorological factor in the model was rainfall in May, followed by rainfall in June. High water content could provide higher ability for increasing the rate of photosynthesis. Minimum temperatures during spring and summer were also an important consideration due to the influence of night temperature on energy collected for fruit development (Wielgolaski, 1974). And, autumn is the key season for fruit development. For this reason, different equations were constructed for different periods of the year. Results were compared with real olive crop data and estimates from the Agriculture and Fisheries Department of the Andalusian Regional Government (AFDA) at different times of the year. Using aerobiological and meteorological data from May to October, a formula was obtained yielding a coefficient of determination of 83%. Moreover, it was the most accurate forecasting model for the 2001/2002 harvest. As the pre-harvest season advanced, the coefficient of determination improved which could be due to the fact that in later models PI and meteorological information from a longer period were included in the formulae, which may indicate that PI is a main predictive variable in olive crop production. In general, both AFDA and aerobiological forecasts were accurate enough for the 2001/2002 harvest, however, the aerobiological method is more objective and it also enables estimates of crop production several months in advance.

Integrating aerobiological, field phenological and meteorological data is an important advance in estimating olive crop production. The reliable results confirm the validity and accuracy of the globally used Hirst volumetric traps as a tool for olive crop yield forecasting in high density olive-growing areas such as the province of Córdoba (Spain). Pollen content in the air can provide accurate predictions of expected olive yield up to 8 months in advance. This is an asset in enabling farmers and governments to better plan marketing strategies and define agricultural policy amongst European Union countries.

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