



Effect of agrometeorological parameters on the phenology of pollen emission and production of olive trees (*Olea europea* L.)

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Abstract

The pollination period and pollen concentration of olive trees (*Olea europea* L.) and olive production were analysed for Prato and Florence using a data set of 8 years (1991–1998). Meteorological data have been used to obtain information about weather conditions during vegetative seasons and correlations were found both for the phenology and yield.

The results showed that air temperature previous to the onset of flowering is of great importance in determining the reproductive cycle of olive tree but the chill period in January and February should also be considered. Olive pollen collected during the pollination period was positively correlated with the production level for both sites. Weather condition following pollination were also taken into account for a better assessment of the final yield.

Abbreviations: CV – Coefficient of Variation, is the percentage ratio of standard deviation and the mean; GDD – Growing Degree Day was calculated starting from 1st January using 5 °C as threshold temperature; DOY – Day Of Year; MPA – Main Peak Appearance date; MPP – Main Pollination Period, the days of the year when the pollen collected is included between 5% and 95% of annual total; DOY MPP – DOY when MPP starts; ND – Number of Days; STDD – Standard Deviation in Days, is the ratio of standard deviation and average daily accumulation of the stage; SPI – Seasonal Pollen Index, daily pollen concentration from the beginning to the end of MPP; r^2 – Determination Coefficient (* = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$).

1. Introduction

Pollen emission analysis were generally conducted to find a relationship between seasonal course of airborne pollen concentration and the final yield. Crop forecasting, in fact, is one of the main topics in product market: it gives information for harvest planning, price policy and stock management. Moreover on the basis of the forecasted production level, other cultivation methods (such as crop pruning and fruit thinning) can also be planned to avoid inter-annual variation of production (Gonzalez Minero et al., 1998).

Many aerobiological studies also focussed on the analysis period of pollen emission, with a particular interest in the allergenic pollens such as those belonging to Compositae, Betulaceae, Urticaceae, Graminaceae and Oleaceae (Spieksma, 1988; Frenguelli et al., 1989).

With respect to olive trees (*Olea europea* L.), airborne pollen captures can be used both to develop forecast model of seasonal pollen emission and a final yield forecast model. A general relationship between fruit production and the amount of airborne pollen has been proposed since the 1960s (Cour and Richard,

1992). This method was used in crop forecasting of olives, vines, cereals, citrus fruits and hazelnuts (Cour and Villemur, 1985; Besselat, 1992; Calleja and Abid, 1992). The method however presents some limitations mainly concerning the period between flowering and harvest. Using the atmospheric pollen concentration as input, no information is used for this period and so only a preliminary estimation of potential yield can be provided. To overcome this problem, meteorological data during flowering-harvest period could be used to integrate pollen data and so to obtain a more precise evaluation of crop real production.

Also, olive tree pollen emission forecast and simulation could produce useful information especially from a medical point of view, because it is one of the most clinically important allergens (D'Amato and Spieksma, 1991). Moreover, the analysis of pollen emission dynamics can represent a basis for a better evaluation of crop phenology and hence an improvement of crop management (fertilisation and crop protection) (Moriendo et al., 1998).

The main driving parameter of this process is temperature which represents the most relevant climatic variable affecting the plant physiological processes. Inter-annual variability of the pollination period is generally forecasted by linear regression with temperature of the preceding months (Frenguelli et al., 1989; Gonzalez Minero et al., 1998). GDD is the approach generally used to describe and simulate the phenology of pollination (Frenguelli et al., 1989; Alcalá and Barranco, 1992).

Our analysis was performed in Tuscany (Florence and Prato) in order to characterise olive tree production and phenology in a large cultivated area. Weather, pollen and yield data were analysed to emphasise the main relationships between pollen phenology and crop production. Finally results were discussed with the aim of obtaining forecasting and simulation models.

2. Materials and methods

The research was performed in Florence and Prato (Figure 1) areas located in the Tuscany region (central Italy). Daily pollen concentration data were collected by the Italian Association of Aerobiology from 1991 to 1998. Airborne olive pollen were counted using a Hirst type sampler (1952), model VPPS2000 Lanzoni. The samplers were placed respectively on the roof of the Florence General Hospital (48 m

a.s.l., 79.5 km from seaside) and in Prato (74 m a.s.l., 67.7 km from the seaside) on the roof of the ARPAT building (the Tuscany Regional Environmental Protection Agency) in order to be completely exposed and to avoid the effects of surrounding obstacles on pollen diffusion.

The starting and the end dates of the Main Pollination Period (MPP, the days of the year when the pollen collected is included between 5% and 95% of annual total) (Pathirane, 1975) and the main peak appearance date (MPA) were calculated for each year. Meteorological historical series for Prato and Florence were provided by the Laboratory for Meteorology and Environmental Modelling (LAMMA) and the Ximeniano Centre for Meteorology. Olive tree production data were supplied by Florence district department (Provincia di Firenze).

Several indexes were used to analyze meteorological conditional effect before bloom phase (generally occurring at the sites in the first 10 days of June). In particular for the time of pollen emission forecast, mean temperatures of January, February, March, April and May and the number of days where mean temperature was below threshold temperature (5°C) in January and February ($\text{nd} < 5^{\circ}\text{C}$) were taken into account (Franguelli et al., 1989; Alcalá and Barranco, 1992). In order to stimulate pollination phenology the Growing Degree Days (GDD) were calculated starting from 1st January using 5°C as threshold temperature (Dennis, 1984; Franguelli et al., 1989).

Total pollen emission during MPP, total annual rainfall, rainfall prior and following bloom period, maximum temperature during MPP phase and length of MPP were calculated and tested to find the best yield predictors according to Gonzalez Minero et al. (1998).

3. Results and discussion

The yearly trend of daily pollen concentration expressed as 7-day moving averages in Florence and Prato stations is shown in Figure 2. The curve is characterised by a fast increase starting from mid-May and reaches its peak at the beginning of June. Then the pollen concentration slowly decreases.

Pollen collected during MPP was expressed as a Seasonal Pollen Index ($\text{SPI} = \text{daily pollen concentration from the beginning to the end of MPP}$; the SPI is dimensionless). SPI resulted higher for each year in Prato than in Florence (Table 1). However high

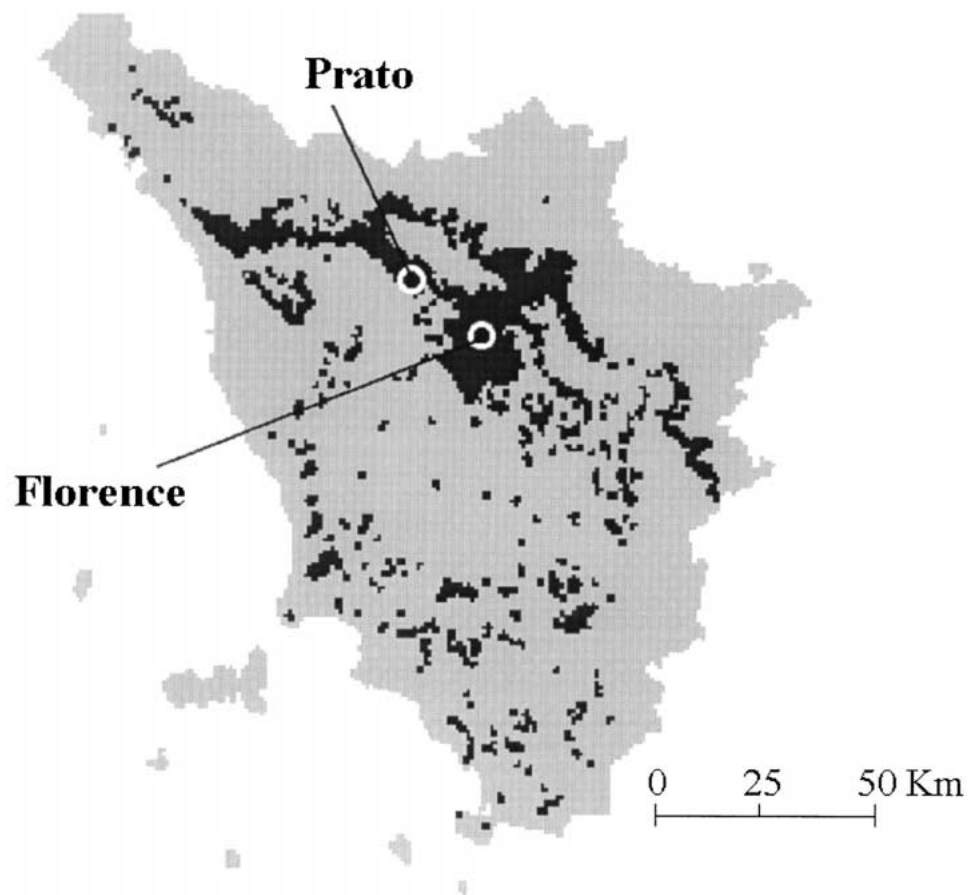


Figure 1. Tuscany map shows olive production areas (Corine Land Cover).

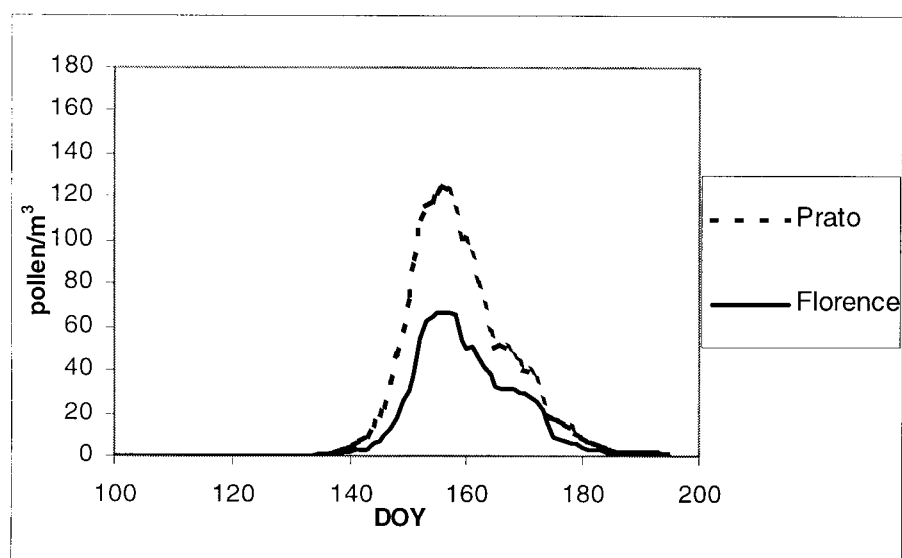


Figure 2. Pollen emission in Florence and Prato stations (7 days moving average).

Table 1. MPP parameters of Florence and Prato

	SPI		MPP beginning (DOY)		MPA (DOY)		MPP duration	
	Prato	Florence	Prato	Florence	Prato	Florence	Prato	Florence
1991	2214	1231	160	159	166	168	19	16
1992	2455	1693	143	146	152	152	23	20
1993	735	529	155	148	158	157	12	13
1994	3342	1638	143	153	151	152	20	10
1995	1945	1167	153	155	160	160	20	22
1996	2180	1702	150	152	157	155	15	13
1997	1243	597	138	141	148	152	24	19
1998	2152	411	148	146	155	155	10	11
mean	2033.2	1121.0	148.7	148.7	155.8	156.3	17.8	15.5

Table 2. Regression coefficient between MPP beginning date and meteorological parameters

MPP beginning date predictors	Determination coefficient	
	Prato	Florence
January	ns	0.54*
May	0.47*	0.69**
nd < 5 °C	0.89***	0.76**
March, nd < 5 °C	0.89**	0.89**
April, nd < 5 °C	0.89**	0.78*
May, nd < 5 °C	0.89**	0.78*
March April (mean), nd < 5 °C	0.91**	0.92**

Table 3. Regression coefficient between MPA date and meteorological parameters

MPA date predictors	Determination coefficient	
	Prato	Florence
January	ns	0.62*
May	0.60**	0.80**
nd < 5 °C	0.89***	0.73**
March, nd < 5 °C	0.89**	0.82*
April, nd < 5 °C	0.89**	0.85*
May, nd < 5 °C	0.92***	0.86**
March April (mean), nd < 5 °C	0.89**	0.88**

variability in seasonal pollen concentration according to the year has been observed both in Florence and in Prato station. SPI in Florence ranges from 411 in 1998 to 1702 in 1996, while in Prato from 735 in 1993 to 3342 in 1994.

The start of the pollination period varies depending on the year and generally an analogy was observed between Florence and Prato (as suggested also by the mean): the earliest was in 1997 (DOY 138 for Prato and DOY 141 for Florence) and the latest in 1991 (DOY 160 for Prato and DOY 159 for Florence). Also MPA showed the same trend. MPP duration showed a different trend in the 2 sites: it ranged from 24 days (1997) to 10 days (1998) in Prato and from 22 days (1995) to 10 days (1994) in Florence.

Parameters, describing general meteorological conditions of the 2 sites in winter and spring, were taken into account first separately (Jan., May and nd < 5 °C) and then together (months + nd < 5 °C) to

forecast MPP and MPA dates (Tables 2, 3). For simple regressions, mean monthly temperatures were negatively correlated with MPP and MPA dates, but the correlation was not always significant. In particular, January results significantly correlated with the variables in Florence while May mean temperature was correlated in both sites. Results improved in simple and multiple regressions when the number of days from January to February below 5 °C were used (nd < 5 °C). Very significant correlation were observed in both sites regressing only with nd < 5 °C (Figure 3). Increasing mean temperature makes early MPP and MPA timing, while the effect of chill period determines a delayed pollination period (data not shown).

The result suggests that mean temperature prior to the flowering period plays a very important role in determining the phenology of pollination period, as reported also by other authors (Alcala and Baranco, 1992; Frenguelli et al., 1989; Gonzalez Minero et

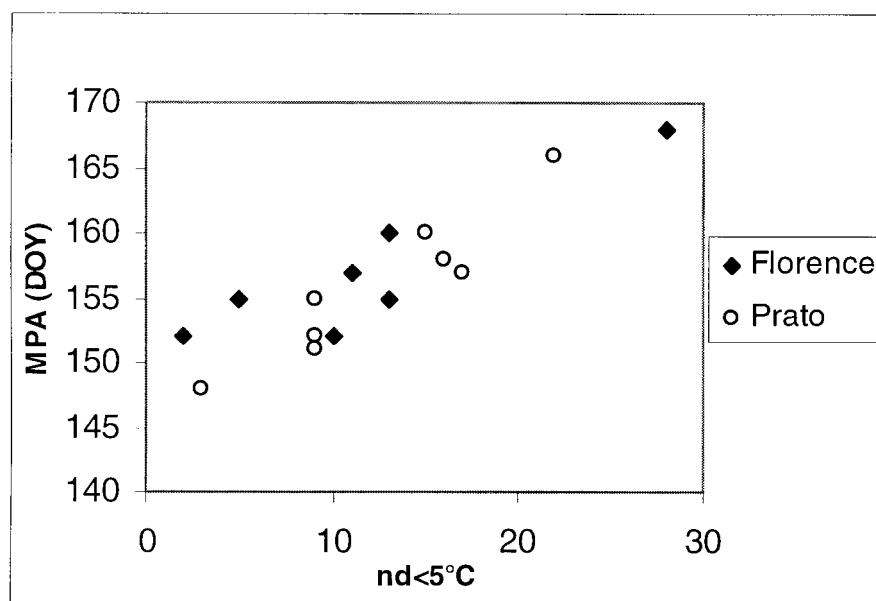


Figure 3. Relation between $nd < 5^{\circ}\text{C}$ in January and February and MPA date in Florence and Prato.

al., 1998). In our analysis, however, the number of chill events in winter provided a better result than the mean temperature allowing a better predictability of the process especially in the early season. The correlation coefficients calculated for MPA and MPP using January and February weather conditions (negative for mean temperature, positive for $nd < 5^{\circ}\text{C}$) in both sites suggests that the olive tree started to accumulate heat units since January and the GDD calculation could start from January 1st with a good correspondence with crop phenology.

GDD required to reach the main phases of MPP was calculated for each site and compared (Table 4). The ability of the model to describe the process was expressed in terms of inter-annual variability of heat units using standard deviation in days (STDD) (which is the ratio of standard deviation and average daily accumulation of the stage) and coefficient of variation CV (which is the percentage ratio of standard deviation and the mean and has a value of zero for an ideal indicator where there is no inter-annual variability) as indexes. Moreover the results obtained from the GDD model were compared to CV and STDD of average number of days (ND). The variability of this simple measure is a baseline indicator upon which any other measure must improve to be more useful (McIntyre et al., 1981).

The GDD amount to reach beginning of MPP and MPA denotes a greater need of heat units in Florence

Table 4. Comparison between GDD and ND model performances in Prato and Florence

	Starting MPP date		MPA date	
	Prato	Florence	Prato	Florence
GDD	903	1035	1013	1142
STDD (GDD)	8	3.78	9.4	3.61
CV (GDD)	0.05	0.026	0.06	0.023
ND	148.7	148.7	155.8	156.3
STDD (ND)	7.24	6.13	5.6	5.4
CV (ND)	0.048	0.041	0.036	0.035

(beginning of MPP = 1035, MPA = 1142) than in Prato (beginning of MPP = 903, MPA = 1013) and ANOVA showed significant difference ($P < 0.05$) for both indexes. However, the difference observed in GDD accumulation could be caused by the heat island effect that affected Florence weather station measurements located in the center of the city. The GDD variability, expressed both as CV and STDD, for Florence was lower than that observed in Prato. According to the comparison of GDD and ND variability in each site (CV and STDD), the GDD calculated in Florence provided a reliable phenology model since variability resulted lower than ND while for Prato ND and the GDD showed quite the same variability.

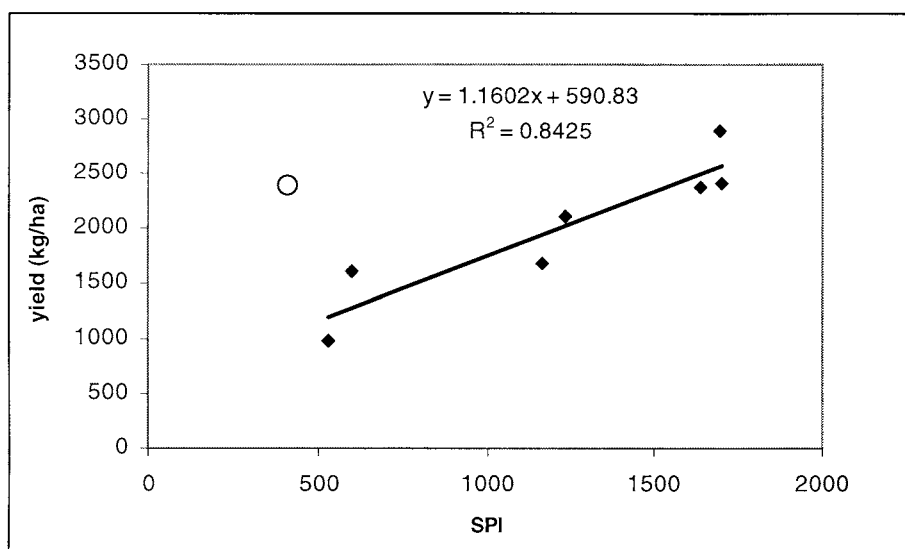


Figure 4. SPI and production regression for Florence. Deleted point is underlined.

Table 5. Relation between meteorological and phenological parameters and final yield in Florence (legend: 6 = June, 7 = July, 8 = August)

Florence	r^2	coefficients			
		intercept	pollen	rainfall	DOY MPP
SPI	0.84**	590.8	1.16		
SPI, rainfall (6 + 7 + 8)	0.87*	301.2	1.08	2.9	
SPI, rainfall (6 + 7)	0.95**	225.0	0.95	6.2	
SPI, rainfall (6)	0.95**	15.6	1.18	8.7	
SPI, rainfall (6 + 7), DOY MPP	0.98**	2397.9	0.98	6.2	-14.8

Regarding the analysis of production, as expected, the results showed a positive correlation between SPI and olive final yield in the analysed sites even if for Florence the significance level was slightly higher than the chosen threshold of significance ($r^2 = 0.42$, $P = 0.07$ for Florence and $r^2 = 0.69$, $P < 0.01$ for Prato). However, for Florence the year 1998 was abnormal because pollen captures were largely affected by heavy rainfalls during the pollination period. In 1998, the highest pollen concentration occurred on day 155 and the MPP ended 2 days later while a rainfall of about 107 mm and 36 mm were recorded respectively on day 157 and 162. Since in this year SPI results were very low (411) even when a high level of olive production (2359 kg/ha) was recorded, rainfall during MPP was held responsible for scarce pollen captures. A new regression

was obtained with a higher level of significance (Figure 4).

To improve forecast reliability the production was regressed adding other parameters to SPI (Lavee, 1994; Maracchi et al., 1994; Rallo, 1994; Gonzalez Minero et al., 1998), such as annual rainfall, rainfall prior to and after the pollination period, maximum temperature during MPP, duration of MPP etc. (Tables 5, 6). Particularly for Florence, rainfall during June added to the SPI, substantially increased the predictability of the production, obtaining a higher r^2 and significance level. This confirms that drought periods are not favourable during production especially during flowering phase and fruit set.

Start date of MPP was also shown to have an effect on the final yield suggesting a positive effect of early bloom period on fruit set and production.

Table 6. Relation between meteorological and phenological parameters and final yield in Prato (legend: 6 = June, 7 = July, 8 = August)

Prato	r^2	coefficients			
		intercept	pollen	rainfall	DOY MPP
SPI	0.69**	826.8	0.60		
SPI, rainfall (6 + 7 + 8)	0.76*	340.7	0.61	3.4	
SPI, rainfall (6 + 7)	0.75*	565.3	0.55	3.3	
SPI, rainfall (6)	0.77*	599.5	0.59	3.6	
SPI, rainfall (6 + 7), DOY MPP	0.83*	4150.5	0.54	3.6	-23.0

Also for Prato rainfall was shown to be positively correlated to production even if, according to the regression significance level, SPI resulted in a better yield predictor. However other parameters, such as rainfall in summer and the start date of MPP, provided significant relation.

4. Conclusions

As expected, temperature is the main parameter driving pollination phenology. The results moreover emphasizes the effect of chill period that should be taken into account for a more reliable forecast both for beginning and main peak emission rate.

As expected, SPI was shown to be positively correlated to olive production in both sites. Results showed a positive effect due to rainfall and a negative effect due to start date of MPP.

Early flowering and high rainfall during summer are factors that influence positively the final yield. In fact water stress during this phase causes early fruit loss (Pandolfi, 1959; Maracchi et al., 1994).

Good reliable yield forecast models can help the economy of both sites. In other words the prices can be established using the models starting from the bloom phase. These results can also be used in allergy prevention centres to predict high risk periods.

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