

Prediction of annual variations in atmospheric concentrations of grass pollen. A method based on meteorological factors and grain crop estimates

J. SUBIZA, J. M. MASIELLO, J. L. SUBIZA, M. JEREZ*,
M. HINOJOSA and E. SUBIZA

*General Pardiñas Center of Allergy and Clinical Immunology, Madrid, Spain and *Botanical Royal Garden, Madrid, Spain*

Summary

We performed an aerobiologic observation of the grasses present in Madrid for 14 years (1978–1991), using volumetric air samplers. The counts obtained show that the major grass pollen release period (average daily grass pollen counts > 50 grains/m³ of air) occurs in the months of May and June, although lower counts can occur some days from the end of January onward. There are wide year-to-year variations in total atmospheric grass pollen counts, expressed as the total sum of the mean daily concentrations from April 1st to July 30th (ranging from 2568 to 6624). A strong, statistically significant correlation, based on Spearman's rank test and/or simple and multiple linear regressions, was found between the total grass seasonal count and preseasonal rainfall from October to March ($R^2=0.64$; $P=0.0429$). The meteorological variable which gave the correlation with greatest statistical significance ($R^2=0.97$; $P=0.0016$) was the average monthly preseasonal humidity from October to March. A good correlation was also found between March estimates of wheat, rye and barley crops and the total grass count ($R^2=0.73$; $P=0.006$). A model was designed from the above mentioned humidity variable through a multilinear regression analysis, and it was possible to predict, at the beginning of April, total seasonal counts for 1989 (predicted=5468; actual=4410; average error=24%), 1990 (5033; 6090; –17%) and 1991 (3930; 2568; 53%). These data may help clinicians to predict and prepare themselves for the intensity of the grass pollen season and to explain yearly variations in the severity of symptoms.

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Introduction

It is well-known that grass pollens are by far the most important cause of rhinitis and/or seasonal asthma in Spain as well as in the majority of other Western European countries [1–8]. In those regions of Spain with a continental climate, like Madrid, the peak of anthesis of most grass species occurs typically from mid-May to mid-June. The beginning of pollination basically depends on the temperature accumulated over the preceding months, which in turn is a function of latitude (pollination is earlier in the south than in the north) and altitude (at the same latitude, pollination is later in the mountains than

on the plains) [5,8–11]. With the help of pollen calendars, statistical analysis of the temperature in preceding months or phenological methods prepared for each geographical area, the beginning and duration of the grass pollen period can be predicted with some accuracy [12–15]. However, in many countries or regions, the severity of the season continues to be a surprise to patients as well as doctors because of the wide variations in atmospheric grass concentrations from year to year [5,12,13,16]. Hence, the importance of the prediction of the intensity of the grass pollen season for clinical purposes. On the basis of 14 years of aerobiologic observation, we found that if an appropriate combination of meteorological variables was submitted to a multilinear regression analysis, it was possible to design a model

Correspondence: Dr J. Subiza, Calle General Pardiñas 116, 28006 Madrid, Spain.

by which we could predict with some accuracy at the beginning of April the total grass pollen counts in the Madrid area for the 1989, 1990 and 1991 seasons.

Materials and methods

Pollen counts

The pollen count was made according to a previously described technique [5,17] with a volumetric spore trap. A Hirst spore trap (C. F. Cassella Co., London, U.K.), was used from 1978 to 1981 and a Burkard trap (Burkard Manufacturing Co., Rickmansworth, Herts, U.K.) from 1982 to 1990. The traps were installed on the roof terrace of our centre which is 20 metres high and is located in the north-east of the Madrid urban area, with no parks or gardens nearby. Ten litres of air are sucked in every minute ($14.4 \text{ m}^3/24 \text{ hr}$) through an opening ($14 \times 2 \text{ mm}$) permanently oriented in the direction of the wind thanks to its built-in vane. The particles found in the air sucked in fall upon a strip located very close to the opening. The strip is a transparent plastic film which we cover with a thin, uniform layer of filamentous vaseline and which is fixed around a drum, rotated by a 7-day clockwork at a speed of 2 mm/hr. Every week this strip is removed and cut into 48 mm long segments, each of which corresponds to one day of sampling. Each segment is mounted on a slide and covered with a $22 \times 50 \text{ mm}$ cover which overlays the area of impact and is adhered to the strip by means of 2–3 drops of a solution of glycerol jelly and phenol at 40°C . In order to study the pollens which have fallen in a 24 hr period, a 48 mm sweep ($2 \text{ mm} \times 24 \text{ hr} = 48 \text{ mm}$) with the immersion lens is made ($\times 10$ ocular, $\times 100$ objective and microscope field diameter of 0.18 mm). The counts made in this 48 mm sweep, once multiplied by a conversion factor of 5.4, give us the average number of grains of pollen per m^3 of air/24 hr.

The sampling period included the months of April–July in 1978, January–December from 1979 to 1990 and January–July in 1991.

Meteorological data

The average daily and monthly temperatures, total monthly rainfalls, average monthly humidities and total monthly sunshine corresponding to the months (October–March) preceding each pollination season, as recorded in the meteorological station closest to our trap (the Retiro station located approximately 3 km to the south) were provided by the data bank of the National Meteorological Institute.

Agricultural statistics

The estimates made in March of wheat, rye and barley production in the Madrid province (kg of grain/ha sown),

Table 1. Degree of precision in the March estimates of grain crops (rye, wheat and barley)

Year	Production (kg/ha)		Relative margin of error (%)
	Estimate	Actual	
78	4526	4556	−0.6
79	4946	4000	23.6
80	4929	5406	−8.8
81	4233	4141	2.2
82	3427	3162	8.3
83	3400	3339	1.8
84	6345	6048	4.9
85	6122	5689	7.6
86	5370	4323	24.2
87	4703	4864	−3.3
88	6105	5763	5.9
89	6053	4750	27.4
90	5835	5980	−2.4

Data provided by the Ministry of Agriculture [18,19]

and the final results obtained in October, were provided by the Madrid Agricultural Board and the Statistics Department of the Ministry of Agriculture [18,19] (Table 1).

Statistical analysis

The following statistical techniques were used to analyse data: a Spearman rank test and a linear regression to investigate the correlation between each meteorological variable and the production of each grain crop and the accumulated grass pollen concentrations for each season, expressed as the total grass pollen April–July (TGPAJ). A multilinear regression was used to predict atmospheric concentrations of TGPAJ from a combination of the above-mentioned variables. The statistical significance of the correlation was evaluated by the Student's *t*-test for simple regressions and by the Behrens-Fisher-Snedecor *F* for multiple regressions.

A PC-AT was used for the statistical study with the following statistical programs: Lotus 123, Lotus Development Corporation, U.S.A.; MicroTSP, Quantitative Micro Software, U.S.A., and Microstat, Ecosoft, U.S.A.

Results

Pollen counts

The grass pollen counts are shown in Figs 1 and 2 and Table 2. The start of the major grass pollen release period,

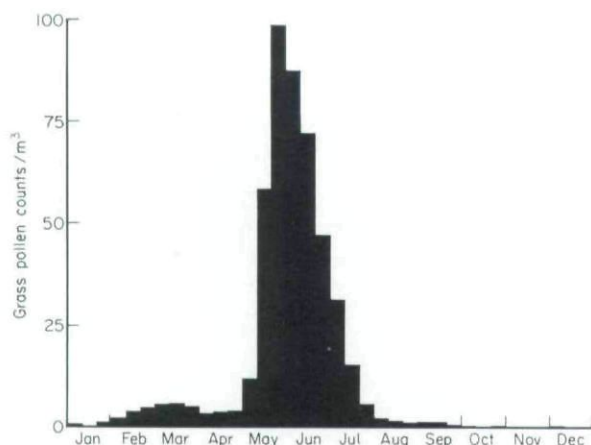


Fig. 1. Madrid grass pollen season. Ten days running means of daily averages of airborne grass pollen concentrations in various years from January 1, 1979 to December 31, 1990.

defined as the day on which a concentration ≥ 50 grains/ m^3 of air occurs [12], varied between 9 and 29 May, although lower values were recorded on some sunny days from the end of January onwards. The end of the major grass pollen release period (last day on which ≥ 50 grains/ m^3 of air are recorded) varied between 18 June and 25 July.

It has been observed (Frankland & Davies, unpublished; referred to by [12]), that when the mean daily concentration of grass pollen grains in the air over Central London is ≥ 50 per cubic metre, practically all the patients in the area who are clinically sensitive to grass pollen experience symptoms. We found in every year sampled in Madrid consecutive days with more than 50 grass pollen grains/ m^3 with a range between 18 in 1991 and 39 in 1985. In fact, in terms of grains/ m^3 of air, grass pollens represent 16.6% of the total annual pollen count, and are only surpassed by *Quercus ilex* pollen which represents 17.5% of the year's total. It has also been observed that grass pollens represent the major pollen allergen in this area and sensitize up to 97% of pollen-allergic individuals. On the contrary, only 5% of these individuals showed allergy to *Quercus ilex* pollen [2,5-6].

Poa annua (winter grass) is the first species to flourish [5], and it probably is the cause of the grass pollen counts that appear on sunny days at the end of January, with a highest preseasonal concentration in March (Fig. 1). However, the major grass pollen release period occurs typically from mid-May to mid-June. These two months (May and June) account for 79% of the year's grass pollen loads, and if the figures for April and July are added, this increases to 92% of the year's total grass pollen (Fig. 1).

This short but intense grass pollinization is mainly due

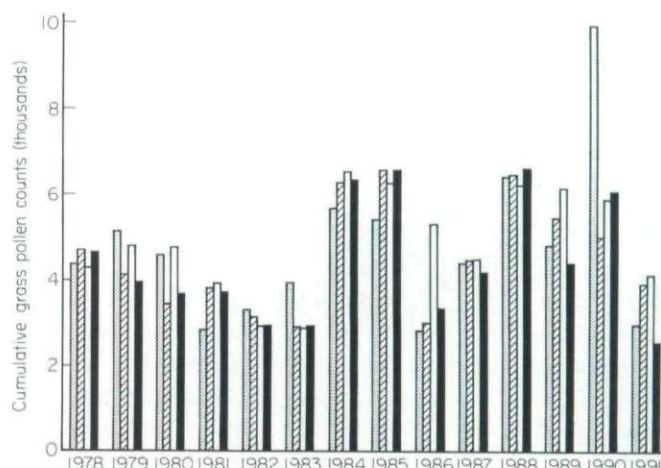


Fig. 2. Comparison between total seasonal atmospheric grasses measured (the sum of daily averages from April 1 to July 31) and grasses estimated from regression formula 1 (calculated on the basis of preseasonal rainfall), formula 2 (calculated on the basis of average preseasonal humidity) and formula 3 (calculated on the basis of the grain crop estimates RWBCE). ▨, rainfall. ■, humidity. □, RWBCE. ■, actual.

to the climatological conditions typical of this geographic area. Madrid is located in the centre of the Iberian peninsula, more than 300 km from the nearest coast. Oceanic humidity cannot penetrate into the peninsula due to the numerous mountain ranges which practically wall off most of the coastal areas (Spain is the most mountainous country in Europe after Switzerland). This endows Madrid (as well as the majority of the other geographical areas in the interior of the peninsula) with the low relative humidity which conditions its continental climate. The lack of humidity in the continental climate is largely responsible for significant daily variations in the thermometer and above all for very brusque changes in temperature with the change of seasons. Very cold winter temperatures turn into very hot summers in scarcely 4 weeks (mid-May to mid-June) and finally provoke an almost simultaneous anthesis of the majority of grass species in the area [8,20].

The species that are likely to contribute most significantly to the airborne grass pollen sampled in this period correspond to *Trisetum paniceum*, *Lolium* spp., *Dactylis glomerata*, and *Poa* spp. [5,6], species known for their excellent adaptation to the low humidity soils found in the Madrid area.

As we can see in Fig. 2, the variation in the total daily grass pollen count during the 14 years of observation in Madrid is considerable, ranging from 2568 (1991) to 6624 (1988).

Table 2. Comparison between estimated and measured grass counts

Year	Actual	Total grasses estimated by*			Seasonal intensity	
		Formula 1	Formula 2	Formula 3	Actual	Predicted
1978	4659	4380 ^M (−6)	4707 ^M (1)	4283 ^M (−8)	Medium	Medium
1979	3957	5158 ^M (30)	4130 ^M (4)	4805 ^M (21)	Low	Medium
1980	3670	4599 ^M (25)	3431 ^L (−7)	4784 ^M (30)	Low	Medium
1981	3721	2834 ^L (−24)	3823 ^L (3)	3919 ^L (5)	Low	Low
1982	2929	3297 ^L (13)	3132 ^L (7)	2917 ^L (0)	Low	Low
1983	2921	3941 ^L (35)	2906 ^L (−1)	2883 ^L (−1)	Low	Low
1984	6354	5678 ^H (−11)	6287 ^H (−1)	6545 ^H (3)	High	High
1985	6592	5426 ^M (−18)	6591 ^H (0)	6268 ^H (−5)	High	High
1986	3359	2833 ^L (−16)	3009 ^L (−10)	5333 ^M (59)	Low	Low
1987	4200	4405 ^M (5)	4485 ^M (7)	4503 ^M (7)	Medium	Medium
1988	6624	6437 ^H (−3)	6486 ^H (−2)	6247 ^H (−6)	High	High
1989	4410	4824 ^M (9)	5468 ^M (24)	6182 ^H (40)	Medium	Medium
1990	6090	9958 ^H (64)	5033 ^M (−17)	5911 ^H (−3)	High	High
1991	2568	2992 ^L (17)	3930 ^L (53)	4145 ^M (61)	Low	Low

* Sum of the daily averages (grains/m³ of air) from April to July. Formula 1 is based on preseasonal rainfall from October to March. Formula 2 is based on average preseasonal humidity (%) from October to March.

Formula 3 is based on March grain crop estimates. The prediction error is expressed as a percentage in parentheses. The intensity of seasonal pollen counts are defined as high H (> 5500), medium M (4000–5500) and low L (< 4000). The definitive estimate corresponds to that which is closest (in terms of intensity) to those predicted by Formulas 1, 2 and 3.

Meteorological data

The only statistically significant correlation found between TGPAJ and meteorological variables was when using rainfall and average preseasonal humidity. On the contrary, no significant correlation was observed with preseasonal temperature and/or sunshine.

Relationship between rainfall and atmospheric grass count

When analysing preseasonal rainfall in individual months (October–March) in relation to the TGPAJ, a correlation was found which was not statistically significant ($P=0.16$). This correlation was improved with the October–January rainfall, although it still did not achieve statistical significance ($P=0.07$). The same analysis was made for the rainfall in February and in March and a much poorer correlation was found with a significance rate of 0.49. Nevertheless, the October–January rainfall together with the rainfall in February and March gave a correlation with good statistical significance ($R^2=0.67$; $P=0.0429$).

The TGPAJ were calculated through a multilinear regression equation using a combination of the rainfall data (Fig. 2 and Table 2):

Formula 1: Estimated TGPAJ =

$$22 (\text{OJR}) - 61 (\text{FR}) + 44.7 (\text{MR}) + 1871$$

in which OJR is the total rainfall in millimetres from October to January, FR is that for February and MR that for March.

Relationship between average humidity and atmospheric concentration of grass pollen

In contrast to rainfall, the most statistically significant correlation between preseasonal humidity and TGPAJ was found with the individual months from October to March ($R^2=0.97$; $P=0.0016$). TGPAJ were estimated from the equation:

Formula 2: Estimated TGPAJ =

$$54.3 (\text{OH}) + 188.2 (\text{NH}) - 84.9 (\text{DH}) + 166.5 (\text{JH}) \\ 29.9 (\text{FH}) - 72.3 (\text{MH}) - 11715$$

in which OH is the average October humidity in % and NH, DH, JH, FH and MH are the humidities for November, December, January, February and March respectively. The results are shown in Fig. 2 and Table 2.

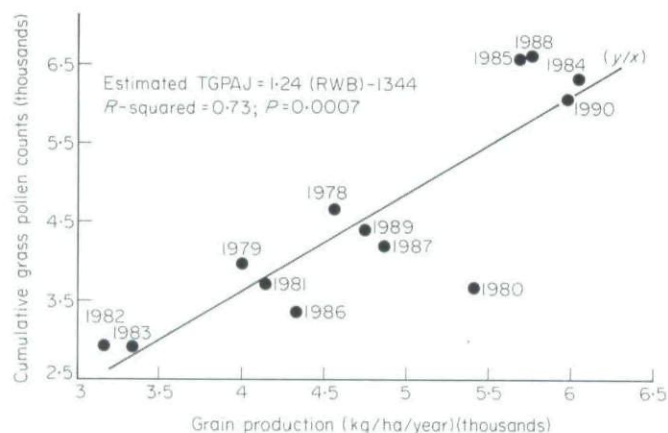


Fig. 3. Regression slope of y on x in which y represents the atmospheric grasses accumulated from April 1 to July 31 (TGPAJ) and x represents the sum of wheat, rye and barley production in the Madrid Autonomous Community (RWB). Note the significant correlation between TGPAJ (1978–1990) and RWB.

Relationship between the grain crop and the atmospheric grass count

As can be seen in Fig. 3, we found a good correlation between grain production, expressed as the sum of rye, wheat and barley production (RWB) and the TGPAJ ($R^2 = 0.73$; $P = 0.0007$). We also found a good correlation between the March grain production estimates (sum of the crop estimates for rye, wheat and barley RWBCE) and the TGPAJ ($R^2 = 0.73$; $P = 0.0006$). TGPAJ were estimated from the equation:

Formula 3: Estimated TGPAJ = $1.24 (\text{RWBCE}) - 1344$

The grass calculated from the RWBCE are shown in Fig. 2 and Table 2.

Relationship between predicted and actual intensity of the grass pollen season

The accumulated grass pollen count between April and June (seasonal total) was classified according to the same criteria used by Davies *et al.* [12] as high (> 5500 grains of TGPAJ), medium (4000–5500) and low (< 4000). We consider the final predicted seasonal intensity each year to be the most frequent result of the intensities estimated by formulas 1, 2 and 3 (Table 2).

Discussion

Previous studies demonstrated that by means of an appropriate combination of meteorological variables, it is possible to predict the atmospheric pollen counts. Estimates have been made with some accuracy, e.g. in the case of *Poaceae* (grasses) [12,21], *Ambrosia* spp. (ragweed)

[22,23], *Betula* spp. (birches) [24] and *Quercus* spp. (oaks) [25]. Davies and Smith [12], through a linear regression formula and using as independent variables the average temperature of April and May and the accumulated daily averages (grass/m³ of air) recorded in May, were able to predict the beginning and the severity of the grass pollination season in London. Likewise, Goldberg *et al.* [21] found a strong dependency between the mean monthly temperature for May and the total amount of pollen from *Poaceae* in the following season, on the basis of data from Copenhagen. However, using an identical methodology, we were not able to demonstrate any correlation between preseasonal temperatures and TGPAJ. On the contrary, a strong correlation was observed between the rainfall and average preseasonal humidity of October–March with regard to the TGPAJ (Fig. 2). This correlation was statistically significant based on Spearman's rank test. Furthermore, a positive correlation was shown through a linear regression equation in that the greater the preseasonal rainfall and humidity, the higher the TGPAJ counts. It is possible that this disagreement with data from London and Copenhagen which show correlations with preseasonal temperature but not with preseasonal rainfall is due to the differences in climate between both England and Denmark (a humid, Atlantic climate) and Madrid, Spain (a dry, continental climate). It should be pointed out that even if the total rainfall of each of the preceding months October–March seems to influence the TGPAJ counts, the October through January rainfall showed the greatest correlation with TGPAJ. This fact is not surprising since the importance of rainfall, above all in Autumn, for the germination and growth of seeds is well-known ('germinal rains'). Nevertheless, the statistical significance could be improved if the rainfalls in February and March were added to the regression equation, since together with the April rainfall, they are considered favorable for sprouting and spiking ('growth rains') [26,27].

One fact which attracts our attention is the negative correlation between rainfall and/or humidity in February and the TGPAJ. This correlation continues to be negative even after adding the experience of years 1989, 1990 and 1991 (data we have not presented) to the multilinear regression equation. In any season, an excess of humidity in the soil is known to suffocate the roots of plants. An excess of rain can also be damaging because it drags nitrates down to a substantial depth and they cannot be used by the roots [25]. Obviously further research is necessary to explain this phenomenon.

The close correlation found between RWB grain production and the TGPAJ counts is remarkable. In effect, a good correlation was found with wheat, rye and barley crops (analysis not presented) although the greatest statistical significance was achieved by the sum of the

three (Fig. 3). It should not be forgotten that these cereals, although now cultivated, are still grasses. Although their pollen grains are relatively large ($> 45 \mu\text{m}$), heavy and are not easily airborne [9, 10] (in fact grass pollens over $45 \mu\text{m}$ do not even represent 1% of the grass grains collected in our traps [5, 6]), all evidence is that the same meteorological variables which affect cereal growth also affect in the same way the wild grasses which, as stated in previous studies, are truly responsible for the atmospheric grass counts [4–6, 8–10]. Nonetheless, the lack of predictive value of this correlation can be suggested since the pollination of grasses precedes the July crops by 2 or 3 months (May–June). However, the crop estimates made in March and published by the Agricultural Board at the beginning of April, which we have shown to give a good correlation with total grass pollen counts, are of use in predicting TGPAJ (Figs 2, Table 2).

Throughout the world, crop estimates are made prior to the date of harvest for various reasons: official promotion by the government of imports or exports according to whether shortages or surpluses are expected, marketing activities, stock forecasts, estimates of damage by the companies insuring the crops, etc. The most efficient procedure for estimating the annual winter grain crops include random sampling techniques carried out in several fields sown with these grains. The crop yield (kg of grain/ha sown) is calculated by the number of stems and/or spikes and/or weight of grain per spike within one sown linear metre. This linear metre is selected at random and represents the sample unit. The size of the sample, or number of sample units which must be used for the study, depends on the degree of precision and the confidence level desired in the estimate as well as on the variation coefficient between the different sample units.

Although this technique is the most objective and efficient method by which to make an estimate in winter of grain crop production, the Madrid Board still uses a survey of local experts and/or farmers [28]. Nevertheless, the calculation error is small as can be seen in the results collected over the last 13 years (Table 1). We believe the correlation found is of interest, first because it may represent a new use for these estimates, and second, because it may possibly be of equal use in predicting TGPAJ in other geographic areas, even if they have different climatic conditions, since these predictions are based on estimates of grain crops made locally and not on meteorological variables.

Based on linear regression formulas 1, 2 and 3, it was possible to predict seasonal airborne grass intensity. It is worthy of note that these predictions not only were possible for the years from 1978 to 1988 (the years used for the statistical analysis) but also for 1989, 1990 and 1991, the data for which were not used in preparing the formulas (Table 2). Even in spite of the fact that the 1990

season was clearly atypical since preseasonal autumn–winter rainfall (precipitation in November/December 1989) was the largest collected in Madrid in the last 27 years and caused an estimate by Formula 1 much higher than the actual figure (9958/6090), this prediction error was corrected by Formula 2 and above all by Formula 3 (5911/6090). It should also be noted that the greatest error in prediction in terms of airborne grass intensity occurred in 1979 and 1980 when the seasonal pollen counts were judged medium instead of low. However, in no instance was a high season pollen count judged as low or vice versa. This holds true not only for the final result but also for the individual results of each of the three formulas.

Nevertheless, establishing a dose response relationship between pollen exposure and symptoms is difficult. The range of severity for individuals is quite broad, and symptoms often reflect concurrent exposure to several allergens. Response usually increases with ongoing short-term exposure (priming), and exposure involves aerosol fractions as well as intact pollen grains [29, 30]. For these reasons, a major question is whether the pollen count and forecast should be given in absolute numbers, instead of relative degrees, since on the basis commented above, what is low for one patient, may be high for another. In terms of absolute counts, it should also be noted that the lowest average error in the last three years predicted was obtained with Formula 2 (24, –17, 53%) as compared to Formula 1 (9, 64, 17%) and Formula 3 (40, –3, 61%) (Table 2).

Various meteorological phenomena (temperature, direction and strength of winds, rainfall, etc.) which occur during the pollination season are known to affect daily pollen concentrations. In previous studies we have found that the abrupt increase in temperature which usually takes place in Madrid from mid-May on (usually after a cold month of April) is well correlated with the height of grass pollination. On the contrary, wind speed and direction as a rule are of minor importance, since Madrid is one of the most stable cities in Spain and usually wind speeds do not reach Grade 2 in the Beaufort scale. Rainfall during this period is rather scarce and although it may clear the air of pollen momentarily, it does not appear to significantly influence the total amount of seasonal pollens [5]. In fact, all data seem to indicate that in this geographical area preseasonal meteorological phenomena influence annual variations in TGPAJ more than those occurring during the season.

In conclusion, the results appear to indicate:

- (i) That grass pollen is very common in the air of Madrid, particularly in the months of May and June. However, there are wide year-to-year variations in the total amount of grass pollen.
- (ii) In general, a strong dependency is found between preseasonal rainfall, humidity and the total seasonal grass

pollens sampled from 1978 to 1991. Humidity and rainfall from October to January appear to be the predominant factors in determining the grass pollen potential for the season in Madrid.

(iii) Through a predictive model based on this average monthly preseasonal humidity parameter, it was possible to forecast the seasonal airborne grass pollen loads for 1989 through 1991 (average error -17 to 53%). These predictions were made at the beginning of April, approximately a month and a half before the height of the grass pollination season.

(iv) A correlation was also found between the airborne grass pollen loads in successive years and grain crop forecasts.

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