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## STUDIES ON THE AIR SPORA<sup>1</sup>

By

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The aim of this study is to provide clinicians interested in allergy with more accurate information on the numbers and types of particles in the air; their seasonal or non-seasonal occurrence; the time of day when they are most abundant in the air, and how they are affected by meteorological conditions. A comparison is made between airborne particles sampled simultaneously in both an urban and a rural site, and a further comparison is drawn between data obtained in two successive years at the urban site.

Most previous aerobiological surveys have used either freely exposed sticky slides or culture plate methods, both of which Gregory (1950) has shown give biased records. An automatic volumetric spore trap (Hirst, 1952) has been used in the present study because it has a relatively high collection efficiency, varying from 55-90 per cent and it is non-selective over the size range 3-40 microns. In this trap, air is drawn through an aerodynamically designed orifice which is directed into the wind and the particles from the air stream are impacted on to a microscope slide coated with petroleum jelly. The slide moves past the air-intake orifice at a constant rate of 2 mm. per hour, enabling rapid fluctuations in the spore load to be traced and compared with meteorological records.

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<sup>1</sup> This paper is based on a thesis approved for the Degree of Doctor of Philosophy in the University of London.

Using this apparatus, a comparison was made between the results from a spore trap erected on the roof of the Botany Department at Imperial College, South Kensington, London, and from a trap in an arable field at Rothamsted Experimental Station, Harpenden, Hertfordshire, a country site 22 miles NNW of London. Both traps were operated continuously from 4 May to 30 September, 1954, the slides being changed each day at about 0900 hours. In 1955 data were obtained from 1 May to 30 September at the London site only.

Each day's catch was mounted and scanned microscopically by making twelve traverses across each slide at distances along the deposited trace corresponding to two-hourly intervals. To identify the spores it was necessary to scan the slide under the oil immersion objective using a fluorite lens with a long working distance. The width of each traverse was 43 microns and by this procedure particles in a sample air volume of 154.8 litres were recorded each day and the numbers converted to an estimated number per cubic metre of air.

Meteorological information for London was obtained from the Air Ministry, Kingsway, and that for Rothamsted from the meteorological enclosure, which adjoined the spore trapping site.

Only elementary statistical methods were attempted in this study. The correlation coefficient " $r$ " was used as a measure of the strength of the relationship between the two-hourly counts of individual pollen grains and fungus spores, and the corresponding temperature, humidity, sunshine etc. figures. Student's " $t$ " test was used to compare the mean counts of fungus spores on hours with rain and hours when no rain fell. The " $F$ " test of significance was used to determine the effect of the time of day of rainfall on the *Cladosporium* count and also to compare the weekly variation in the *Cladosporium* count with variation between the days within each week. Analyses of variance were carried out on the counts of inorganic particles according to wind direction. In all these tests significance was fixed at the five per cent level.

The data from these studies are presented under four headings:

- I Pollen grains
- II Fungus spores
- III Miscellaneous organic particles
- VI Inorganic particles.

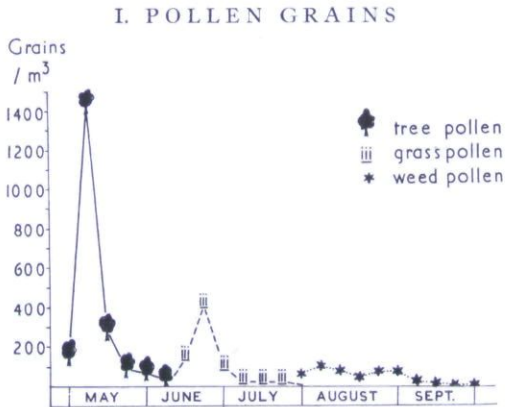


*Fig. 1.*

Airborne pollen grains in London in 1954.

In each year the survey was begun after the flowering of the early catkin-bearing trees, but the succession of flowering of the later trees, the grasses and the dicotyledonous herbs, (termed "weeds") is shown in *Fig. 1*.

The dates of the highest weekly average tree pollen counts were in good agreement with those given in Hyde's tree pollen calendar for Cardiff (Hyde, 1956). The consistent date of flowering of the grasses is a feature of the pollen counts in Britain. As is shown in *Fig. 1* grass pollen was shed in abundance from the first week of June until the third week of July. In 1954, the maximum concentration of grass pollen in the air was not only in the same week in both city and country (20 to 26 June), but the highest daily counts also occurred on the same day, 22 June. Although there were higher numbers of airborne grass pollen grains in London in 1955, compared

with 1954, the dates of maximum production were the same in both years. The average counts of the commonest pollen grains on the slides are given in *Table 1* and it can be seen that the amount of airborne "weed" pollen never reached the quantity of either grass or tree pollen. The dates of "weed" pollen shedding were not consistent for the three sets of data.

TABLE 1  
*Pollen Counts (May-September).*

| Group  | Pollen                          | Average Number per cu. metre of air |             |             |
|--------|---------------------------------|-------------------------------------|-------------|-------------|
|        |                                 | Country 1954                        | London 1954 | London 1955 |
| Tree   | Aesculus (horse chestnut) ..... | 1                                   | 1           | 0           |
|        | Betula (birch) .....            | 5                                   | 4           | 1           |
|        | Corylus (hazel) .....           | 7                                   | 0           | 0           |
|        | Fraxinus (ash) .....            | 4                                   | 1           | 0           |
|        | Pinus (pine) .....              | 5                                   | 3           | 1           |
|        | Platanus (plane) .....          | 1                                   | 80          | 21          |
|        | Quercus (oak) .....             | 13                                  | 6           | 3           |
|        | Tilia (lime) .....              | 1                                   | 0           | 0           |
| Grass  | Gramineae—all species .....     | 58                                  | 38          | 57          |
| "Weed" | Artemisia (mugwort) .....       | 1                                   | 2           | 2           |
|        | Other Compositae .....          | 1                                   | 1           | 6           |
|        | Chenopodium (fat hen) .....     | 5                                   | 1           | 2           |
|        | Ericaceae .....                 | 1                                   | 0           | 0           |
|        | Plantago (plantain) .....       | 2                                   | 12          | 4           |
|        | Rumex (dock) .....              | 2                                   | 2           | 4           |
|        | Urtica (nettle) .....           | 15                                  | 20          | 25          |

Pollen is liberated mainly during the day, and the highest counts were recorded between 1100 and 1900 hours. The diurnal periodicity curves of grass pollen and of *Urtica* (nettle) pollen are given in *Fig. 2*.

As different grasses shed their pollen at different times of the day (Hyde & Williams, 1945) each grass pollen curve is probably a composite one. The double peak in the bar graphs of grass pollen counts at different temperatures, shown in *Fig. 3* also indicates the heterogeneous nature of this group. There was a highly significant correlation between the counts

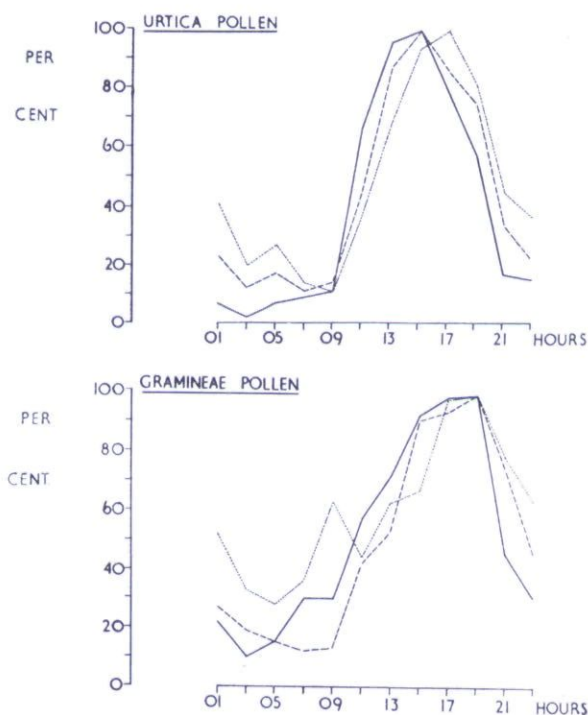


Fig. 2.

The diurnal periodicity of pollen counts.

— Rothamsted, 1954; --- London, 1954 and ····· London, 1955.

of grass pollen from the air and the incidence of bright sunshine, and an inverse correlation between grass pollen counts and relative humidity.

In my study the counts of *Platanus* and *Urtica* pollen were significantly correlated with atmospheric temperatures, and the counts of airborne *Urtica* pollen were found to be significantly reduced by high winds.

Rain reduced the total pollen count (Fig. 4) and the greatly diminished tree pollen count in 1955 compared with 1954 further illustrated this point. In London in 1954 *Platanus* pollen accounted for 46 per cent of the total number of grains caught, but in 1955 *Platanus* was only 16 per cent. There were five wet days in London in May 1954 and fifteen in 1955.

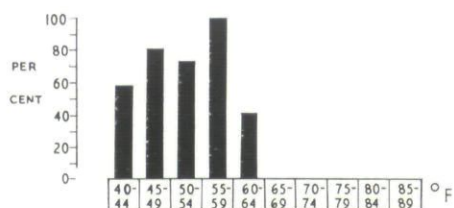
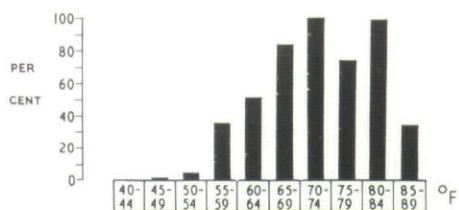
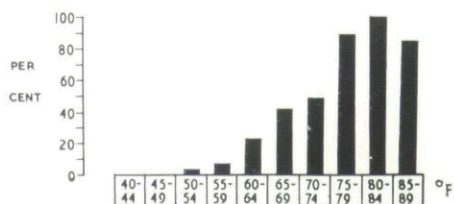
PLATANUSGRAMINEAEURTICA

Fig. 3.

The relationship between pollen counts and temperature,  
London, 1955.

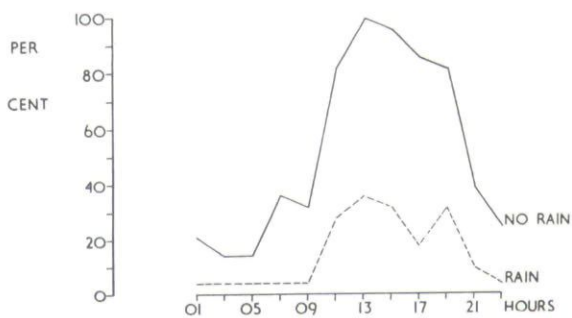


Fig. 4.

The effect of rain on the total pollen count,  
Rothamsted, 1954.

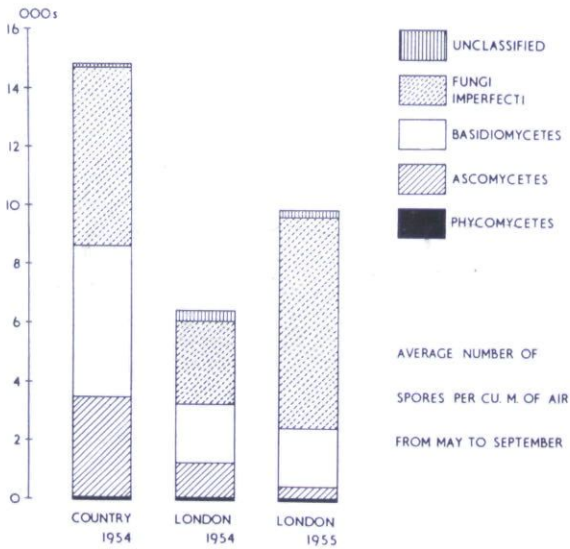


Fig. 5.

Proportions of each class of fungus spore in the air.

## II. FUNGUS SPORES

### Composition of Catch.

The spores of representatives of all four classes of the fungi—Phycomycetes, Basidiomycetes, Ascomycetes and Fungi Imperfecti have been recorded from the spore trap slides. Fig. 5 indicates the proportions in which they were present in the air.

#### 1. *Phycomycetes*.

The small catch of Phycomycetes consisted of the sporangia of *Entomophthora*, *Peronospora*, *Phytophthora*, and the sporangiospores of *Mucor* and *Rhizopus*. Of these only *Entomophthora* occurred in any abundance.

#### *Entomophthora* type.

This insect-attacking fungus is parasitic on aphids, flies and the larvae of butterflies and beetles. The counts of *Entomoph-*

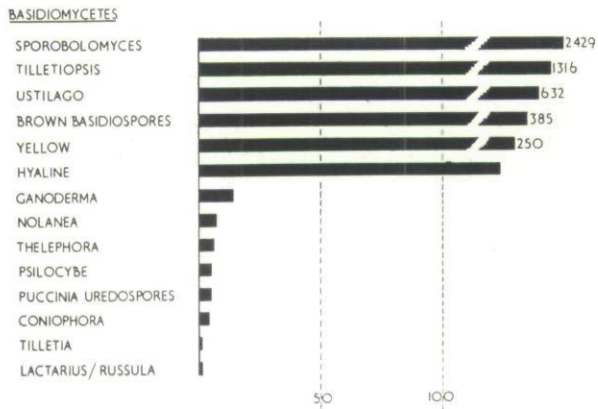


Fig. 6.

Average number of spores per cubic metre of air, Rothamsted,  
May to September, 1954.

*thora* spores began to increase during the second week in June and were highest in late August and early September. There was a marked diurnal periodicity of occurrence with two maxima, the first at 0500 hours and the second at 1300 hours. Rain decreased the number of airborne spores, but high humidity conditions favoured increased counts. Strong winds were associated with low catches of the spores, possibly because of the reduction in the number of the insect hosts. There was a correlation between insect and *Entomophthora* counts which was highly significant in London and significant at Rothamsted. Ali (1957) in laboratory experiments on the behaviour of *Entomophthora* spores in culture also found that the diurnal periodicity showed a double peak, with maxima at 0500 and at 1300 hours.

## 2. *Basidiomycetes*.

The groups into which the Basidiomycetes are divided are given in Fig. 6.

### *Basidiospores*.

In general, brown, yellow and hyaline basidiospores from toadstools, bracket-fungi, fairy clubs, etc. were most numerous

in August and September and the greatest daily concentrations were between midnight and dawn. Rain did not affect the count of hyaline basidiospores, but decreased that of coloured basidiospores. Total basidiospore counts were increased with rising humidity and decreased with rising wind velocity. The concentration of brown basidiospores was increased with higher temperatures but the hyaline and yellow basidiospores were not affected. The diurnal variation of basidiospore counts with higher concentrations at night, follows the daily cycle of temperature lapse rate and its effect on turbulence.

Some basidiospores have microscopic characters which make them readily identifiable and they have been recorded under the following six headings.

(i) *Coniophora* type.

The thin fruiting body of this fungus grows on the ground or on wood, and when mature it is powdered with thick-walled, yellow basidiospores.

(ii) *Ganoderma* type (Druid's saddle).

This is a bracket-fungus growing on the trunks of old beech, oak and other trees. The rust-brown spores of *G. applanatum* have an outer hyaline wall pierced by projections of the inner coloured wall.

(iii) *Lactarius/Russula* type.

The warted spores of this group of toadstools were the only large, hyaline basidiospores to which a name was given in this survey.

(iv) *Nolanea staurospora* type.

This toadstool produced yellowish, quadrangular spores which were identifiable on the slides.

(v) *Psilocybe* type.

A few dark brown, reticulately ornamented spores of *P. foenisecci*, a small toadstool, were collected on the slides during July and August.

(vi) *Thelephora* type.

This fungus is found on wood or on the ground and produces spiny, angular, yellow spores.

*Rusts.*

Rust spores from plant leaves and stems were never very abundant on the spore trap slides. Most common were the uredospore stages of *Puccinia glumarum* (stripe rust) and *P. anomala* (brown rust of barley), while in the warm summer of 1955 *P. graminis* (black stem rust) was recorded. The maximum counts of uredospores were in August and these spores were most numerous in the air at about 1500 hours. Rain and high wind velocity reduced the counts, but the numbers increased with high humidity conditions. Weinhold (1955) showed experimentally that the rate of fall of the uredospores of *P. graminis tritici* increased with rising relative humidity because of the increased weight and size of the spores.

*Smuts.*

The smut fungi attack the stems and leaves of flowering plants, and are apparent as a dark powdery mass on fruiting grasses and cereals. In this survey the most commonly encountered smut was *Ustilago avenae* the loose smut of oats and also of *Arrhenatherum*. The *Ustilago* type of chlamydo-spore is subspherical, brown, echinulate and approximately six microns in diameter. They were frequently found in clumps on the slides and had a well-defined season from mid-June until the end of July, with maximum daily counts in the afternoons. The numbers of airborne smut spores were greatly reduced during rain, and increased humidity also reduced the count.

The meteorological conditions which may have increased the counts included sunshine, high pressure and the gustiness of the wind.

*Tilletia* was the only other smut which was recognized on the slides but the counts were negligible compared with those of *Ustilago* spores. The chlamydospores of *Tilletia* also develop on cereals and wild grasses and they attained their highest incidence in the air in late August and early September.

*Sporobolomyces* type (shadow yeast).

Species of *Sporobolomyces* have been recorded from the living and dead leaves of ferns and flowering plants, where the pattern of the colonies on the leaf simulates the leaf venation. The counts of the hyaline, grape-pip shaped spores were highest in July and August with maximum counts between 0300 and 0500 hours. The numbers increased with rising dew point values and in the country there were high counts during rain: increased wind velocity reduced the concentration of the spores. In London the counts were greatest at temperatures between 60–64° F (16–18° C) and they decreased steadily above this. As stated by Gregory & Hirst (1957) highest concentrations of these spores appear after warm humid nights, followed by early mornings of low turbulence.

*Tilletiopsis* type.

The distribution of this fungus on leaf surfaces is similar to that of *Sporobolomyces*, but the peak occurrence of the hyaline, "hinged" *Tilletiopsis* spores in this survey was in August and September, slightly later than *Sporobolomyces*. Unlike *Sporobolomyces* the numbers of *Tilletiopsis* spores in the air did not increase significantly when rain was falling, but in all other respects these two fungi showed definite similarities, with the same optimum temperature range and the same time of daily maximum occurrence. Weekly average counts of *Tilletiopsis* spores were not significantly correlated with

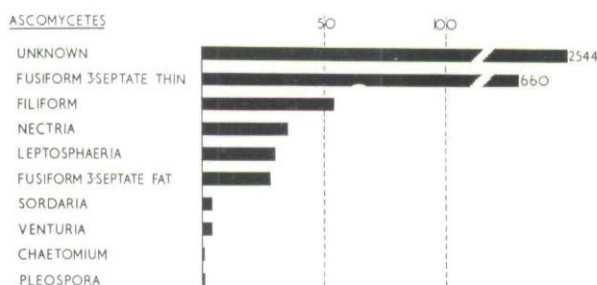


Fig. 7.

Average number of spores per cubic metre of air, Rothamsted,  
May to September, 1954.

any of the meteorological factors tested, but came closest to significance with temperature, dew point and wind velocity data, the factors which affected the *Sporobolomyces* counts.

### 3. *Ascomycetes*.

The groups into which the *Ascomycetes* are divided are given in Fig. 7.

#### *Filiform ascospores*.

These spores are mainly from lesions on plant leaves and stems and have a ratio of length to breadth greater than 20:1. This group included both septate and aseptate spores which were probably ascospores from such genera as *Epichloe*, *Claviceps*, and *Ophiobolus*. There was an increase in the counts beginning about mid-May and the numbers rose to a general peak in July and decreased very gradually. The diurnal periodicity curve showed that the maximum counts were at night. The gustiness of the wind was the only meteorological factor with which the counts were significantly correlated: increased gustiness gave rise to higher spore counts. Gregory & Sreeramula (1958) reported that these spores were completely absent on dry days, but my counts show that although the numbers of these ascospores were significantly higher during rain, they were not completely absent on dry days.

*Fusiform ascospores.*

This was another artificial group of leaf-spot fungi which was further sub-divided into *thin*-three-septate-fusiform ascospores and *fat*-three-septate-fusiform spores. Colourless spores of this type may belong to the Lophiostomataceae, while those which are slightly coloured may be *Leptosphaeria* ascospores. The *thin* type of spore was encountered approximately twenty times more commonly than the *fat*, but both behaved in much the same manner. They gave higher counts during rain and the counts were correlated with humidity. There was a sharp increase in both types of spores at the end of July and peak production was reached in August. In each case the greatest numbers were found at night.

*Leptosphaeria* type.

In this survey only those multiseptate, fusiform spores with one markedly swollen cell and yellow colouring were termed *Leptosphaeria*. Peak concentrations of these spores occurred during the last week of May and the first week of June. The counts were significantly increased during rain and there was no well-defined diurnal periodicity; the numbers were inversely proportional to atmospheric pressure.

*Unequally two-celled ascospores: Venturia* type.

The highest numbers of this type of ascospore were recovered from the air in May. The counts increased during rain and the daily maximum count was between 1100 to 1500 hours.

*Miscellaneous ascospores.*

Other ascospore types which appeared on the slides included small, hyaline, one-septate spores; hyaline rods; oval spores; *Nectria* type; *Chaetomium* and *Sordaria* type. Of these, the rods and the small one-septate spores predominated.

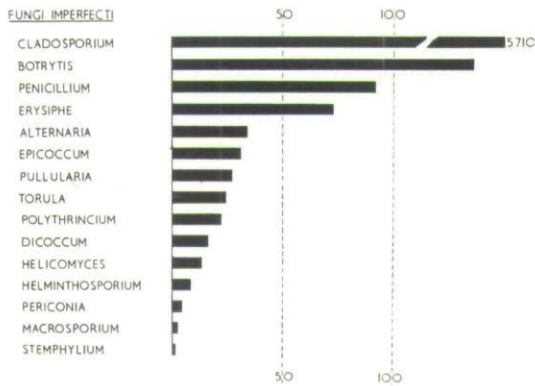


Fig. 8.

Average number of spores per cubic metre of air, Rothamsted,  
May to September 1954.

#### 4. *Fungi Imperfecti*.

The groups into which the *Fungi Imperfecti* are divided are given in Fig. 8.

##### *Alternaria* type.

The conidia caught belonged mainly to the *A. tenuis* group in which the beaks are seldom more than half the length of the conidia (Mason, 1928). The fungus is found on numerous organic materials in damp situations and the highest numbers of airborne spores were on slides exposed in late August and early September. The counts were much higher in dry weather and showed an afternoon maximum. There was a strong correlation with temperature and the range between which most spores were caught was 75–85° F (24–29° C). The counts were strongly correlated with dew point values; very gusty winds increased the counts and the numbers of conidia were reduced at higher barometric pressures.

##### *Botrytis* type (grey mould).

This fungus is found on a wide variety of organic materials and the number of almost hyaline, one-celled, ovoid *Botrytis*

spores in the air, was highest in August and September. The spores occasionally occurred in clumps of about four or five conidia and were most abundant on the slides in the afternoons. The counts were reduced during high winds but increasing temperatures and humidities were associated with rising numbers of *Botrytis* spores.

*Cladosporium* type.

This genus includes both the one-celled conidia formerly known as the *Hormodendrum*-type, and conidia with one to three septa (Bisby, 1944). *Cladosporium* will grow on all manner of organic material. The airborne conidia were occasionally found in clumps and were most abundant in the afternoons. The *Cladosporium* season was from July until September and the highest single count recorded at the country site amounted to 133,000 conidia per cubic metre of air. A comparison of *Cladosporium* figures at times when rain was falling compared with dry hours showed that there was an appreciable decrease in the numbers during rain. Ainsworth (1952), Hirst (1953) and Gregory (1954), working at shorter time intervals than I, demonstrated a transient increase in the numbers of *Cladosporium* conidia when rain started to fall. Hirst (1953) and Sreeramulu (1956) noted that the clumping of *Cladosporium* spores was most common before the daily peak concentration was reached and also at the start of rain. The spore counts were correlated with temperature and the optimum temperature was between 70–79° F (21–26° C).

*Dicoccum* type.

The dark brown, two-celled, spiny conidia of *D. asperum* have not been recorded in previous aerobiological surveys. The fungus grows on leaf surfaces and the spores were most abundant in the air in August and September, with maximum counts in the afternoons. In London the numbers of conidia were decreased during rain, and humidity was found to be the most significant meteorological factor affecting the count.

*Epicoccum* type.

This fungus is found as black dots on dead leaves and stems and on decayed wood. The numbers of these spherical, dark brown, finely warted conidia began to rise in mid-July and maximum counts were recorded at the end of August. There were many more conidia in the air during dry periods and the numbers increased with rising humidity and temperature.

*Erysiphe* type (powdery mildew).

This mildew produces large, hyaline, somewhat rectangular looking conidia on the surface of the host plant. On the spore trap slides the conidia were often in chains of two or three spores. High counts of spores were obtained from 20th June until 10th July with maximum counts in the afternoons. There were more conidia in the air on dry days: high temperature, pressure and humidity increased the counts.

*Helicomyces* type.

The hyaline, coiled conidia of *Helicomyces* develop saprophytically on any vegetable matter. The conidia were most abundant in the air in June and reached an ill-defined daily maximum in the afternoons. In London the counts of this type of spore were significantly higher during rain, but no other single meteorological factor appeared to influence the number of airborne spores.

*Helminthosporium* type.

In this survey the smooth, brown cylindrical one to seven septate conidia of *Helminthosporium* were most numerous in late August and early September. Species of this fungus cause the "stripe" diseases of cereals and grasses, and also occur as saprophytes on plant debris. The number of conidia were much higher when there was no rain, but increased humidity raised the count. There was a significant correlation between the

numbers of spores and the air temperature; high wind speeds reduced the numbers.

*Macrosporium* type.

There is doubt about the correct nomenclature of this fungus and Mason (1928) suggested that it should be named *Thyrospora*.

The obovate, muriform, brown, finely echinulate conidia were airborne at the end of July and in August. The maximum incidence appeared to be in the late afternoons, but the numbers were too low to give a reliable diurnal periodicity curve. Rain decreased the numbers of these conidia in the air; increased temperatures and humidities were associated with higher spore counts.

"*Penicillium*" type.

This was an heterogeneous group comprising all small, spherical spores of a size from three to five microns in diameter, whether they were rough or smooth walled. The group may have included representatives of the genera *Aspergillus*, *Paecilomyces* and *Penicillium*. Most frequently they were found on the slides as chains of conidia and occasionally large numbers had been deposited at one time. The higher counts of the "*Penicillium*" type of spore recorded in London compared with the country site agrees with the findings of Richards (1953) who caught greater numbers of *Penicillia* in the big cities, using a Petri dish method.

The upholders of a seasonal incidence for *Penicillium* find that the maxima are in the spring and winter and this was the trend which was indicated by the seasonal curves in both town and country. A factor in support of this trend was the comparatively low optimum temperature range which was found to lie between 50–54° F (10–12° C). The highest counts were in the afternoons with maximum catches under dry conditions; no other meteorological factor was shown to affect the counts.

*Periconia* type.

The spherical, brown, verrucose conidia of this fungus measure from 10–17 microns in diameter and according to Mason and Ellis (1953) are present throughout the year in Britain. In the present survey, occasional conidia were found from July to September. The conidia were airborne mainly in the afternoons and were almost entirely absent during rain. Rising temperature and humidity increased the numbers caught.

*Polythrincium* type.

*P. trifolii* forms black spots on the under surface of the leaves of *Trifolium repens* (white clover). The numbers of obovate, one-septate, brown conidia of this fungus increased from mid-July and reached a peak at the end of August. Hirst (1953) stated that the highest counts of *Polythrincium* conidia occurred on his slides shortly before noon and I confirmed this for Rothamsted in 1954. The counts of the spores were positively correlated with temperature and humidity; while rain greatly reduced their incidence in the air.

*Pullularia* type.

These are found as "sooty moulds" living saprophytically on leaf surfaces and often on the "honeydew" from aphids. Hawkins (1957), working at Bristol, England, found that *Pullularia pullulans* was the most common isolate from the washings of apple leaves and Hudson & Webster (1958) showed that this fungus was frequently present on grass leaves even before they unfolded. In this survey the counts of *Pullularia* were not recorded as single spores, but as the number of clumps of dark brown, isodiametric cells with rounded sides and thick double walls. Each clump was most frequently composed of ten or more units and the fungus was most abundant in late July, August and September. There was a marked diurnal periodicity with counts reaching a maximum in the afternoons and the numbers trapped were much higher when there

was no rain falling. The numbers of *Pullularia* groups at both sites were correlated with humidity: temperature affected the London counts.

*Torula* type.

The dry spore chains of *T. herbarum* arise in aerial tufts from decayed wood or from the soil, and when mature, the chains fall apart into small lengths of sometimes two, but more frequently four or five spores (Mason, 1941). In the graphs of seasonal incidence there was a tendency towards spring and autumn maxima and the highest daily counts were found around noon. The numbers of airborne *Torula* spores increased with rising temperatures and the numbers were diminished during rain.

### III. MISCELLANEOUS ORGANIC PARTICLES

1. Algal groups.
2. Insect fragments.
3. Mycelial fragments.
4. Plant hairs.
5. Miscellaneous.

#### 1. *Algal Groups.*

Small colonies consisting of from four to eight cells of a unicellular alga of the *Gloeocapsa* type were found regularly on the slides. They were never abundant (maximum 400 per cubic metre of air) and did not show any marked seasonal trend. The average number of colonies trapped over the five months was 8 per cubic metre at the country site in 1954; 4 per cubic metre in London in 1954 and 2 per cubic metre in London in 1955. The maximum occurrence of the alga in the air was in the afternoons. High intensity sunshine increased the algal catches in London, while strong winds gave increases in the country.

## 2. *Insect fragments.*

Insect hairs, scales and occasionally legs or even complete insects were found on the petroleum jelly film, but the complete insects were always removed before mounting a slide. In 1954 the counts of insect fragments were five times greater in the country than in the city. These particles were most numerous in the air in late August and early September with the maximum daily count occurring between late afternoon and dusk. This agrees with Glick (1939) who found maximum numbers of insects at sunset when the crepuscular, the night fliers and the day forms are present. The numbers of insect particles showed a strong positive correlation with both temperature and dew point and the counts were inversely related to wind velocity. The greatest numbers of insect fragments were trapped when the temperature was between 80–84° F (27–29° C).

## 3. *Mycelial Fragments.*

Portions of fungus conidiophores and hyphae were found in the air throughout the five months of this survey. They were mainly dematiaceous hyphae with an occasional geniculate conidiophore recognisable as of the *Polythrincium*-type. In London the numbers of fragments were highest at the end of August, but the country counts reached a sharp peak at the end of July. In 1954 the trap in the country caught twice as many mycelial fragments as its counterpart in the city. A comparison between the two seasons in London showed that in 1955 the number of fragments was almost three times greater than it had been in 1954. There was a well defined diurnal periodicity in the number of mycelial fragments in the air, with a daily maximum between 1500 to 1700 hours. In the city the greatest numbers of airborne mycelial fragments were recovered on warm, dry days, with maximum counts when the temperatures were between 75–79° F (24–26° C). The highest single count was at the country site on 21 July at 1700 hours when a count of 10,400 mycelial fragments per cubic metre of air was recorded.

#### 4. *Plant Hairs.*

Plant hairs were trapped mostly in May and June when they consisted of the soft down from the young leaves of various trees. In London the hairs were mainly from the under side of *Platanus* leaves. Each of these hairs consists of an erect multicellular axis from which numerous tapering branches radiate at intervals. The abundance of *Platanus* around the trapping site in London would account for the total count of plant hairs in the city in 1954 being almost six times greater than in the country. The simple, unbranched hairs of *Platanus* seed were not as commonly trapped on the slides. Other hairs included simple unicellular hairs such as could have come from grasses, and stellate hairs, which are known to be common on the leaves of Cruciferae. The highest count was in London at 1300 hours on 31 May, 1954 when 1,600 hairs per cubic metre of air, were recorded. The daily peak concentration of hairs was at 1300 hours and minimum counts were at 0500 hours. Rain significantly decreased the numbers of airborne hairs, whereas increased wind velocity gave higher counts on the slides.

#### 5. *Miscellaneous.*

A few organic particles were of sporadic occurrence on the spore trap slides. Pteridophyte spores were occasionally found from July to September. Diatoms and desmids made rare appearances on both city and country slides, as did a large, multicellular lichen ascospore. In London in 1954, on two occasions, chains of arthrospores recognisable as of the *Streptomyces* type were found on the spore trap slides.

### IV. INORGANIC PARTICLES

For the first three months of the 1954 survey, counts were made of inorganic particles in the air at both town and country sites. The particles recorded were *ash spheres* from the combustion of solid and pulverised fuels; *smoke groups* comprised

of *aggregates* of smoke particles; soot, and hollow, polyhedral bodies called *cenospheres*, which are formed from pitch, coal or fuel oil in any process involving incomplete combustion.

TABLE 2  
*Highest counts of inorganic particles in London air.*

| Particles          | Number per<br>cu. metre |
|--------------------|-------------------------|
| Ash spheres .....  | 437,400                 |
| Smoke groups ..... | 168,100                 |
| Soot .....         | 113,200                 |
| Cenospheres .....  | 7,700                   |

The counts of ash spheres, cenospheres and soot were lower in July than May, but the counts of smoke groups did not follow this seasonal trend.

In the country, the counts of ash spheres, smoke groups and soot were about half those in London, while the cenosphere count in the country was only one quarter of that in London. Nevertheless, the "clean" air of the country still contained appreciable quantities of inorganic matter, a fact which was stressed by Bloomfield (1955).

The diurnal periodicity of occurrence of inorganic matter in the air was not marked, but did show an early morning maximum at 0700 hours, probably due to the lighting of industrial and domestic fires. An analysis of variance between counts of inorganic material on Saturdays and Sundays compared with week days showed no significant difference in the two groups of data.

There was no significant correlation between the concentration of airborne ash spheres and either temperature or wind velocity. When however, the ash sphere count was analysed with the *product* of temperature times wind velocity a significant inverse correlation was found. A similar result was obtained by Ives, Britten, Armstrong, Gill & Goldman (1936) when they studied atmospheric pollution in 14 American cities and they attributed their result to an increased use of fuel

when the temperature falls, while the increased wind velocity dissipates the particles.

*Wind direction* was shown to influence significantly the counts of inorganic particles. Winds which had blown across London carried significantly higher loads of inorganic matter than winds from any other direction. Airy (1874) operated an aeroscope at Greenwich (5 miles from the centre of London) and found that the NW winds from London brought more soot than the S winds from the country.

It is generally accepted that rain "clears the air", but the counts of ash spheres in London were not decreased either during or after the fall of rain.

#### DISCUSSION

In the past many gravity slide studies on airborne pollen grains and fungus spores have been conducted, and the main components of the catch distinguished although no exact volumetric estimates were made. Most workers adopted the culture plate method of investigating fungus spores in the air, but this technique gives neither a complete qualitative nor makes any attempt to give a quantitative estimate. In such surveys only the spores of the Fungi Imperfecti and Mucorineae grow and are recorded: as may be seen from *Fig. 5* the spores of these two classes may amount to less than half of the total fungus spore count as the *Basidiomycetes* and the bulk of the *Ascomycetes* are not recorded.

The only means of investigating the entire air spora is therefore by a visual method, but even in this errors may arise (a) in scanning when a low count gives an unreliable estimate and (b) in identification. My "*Penicillium*" group needs to be broken into its component fungi and many of the basidiospores and particularly the ascospores await identification.

Pollen catches in all three surveys were composed of the same genera of anemophilous plants. Grass pollen amounted to 44 per cent of the total pollen catch in the country in 1954, with an average count of 58 grains per cubic metre of air: all the

tree pollen grains (except *Platanus* and *Aesculus*) were most numerous in the country. The dates of maximum incidence of grass pollen were constant for the three groups of data, but the pollen shedding dates of trees and "weeds" showed more variation. All pollen grains were most abundant in the air in the afternoons. The proportion of pollen grains to fungus spores was of the order of 1:75.

The total counts of fungus spores in the city in 1954 were less than half those *in* the country (see *Fig. 5*), but the city counts were high nevertheless and averaged 6,500 spores per cubic metre of air in 1954 and 9,500 in 1955. It is noteworthy that in both city and country the same twelve groups comprised the most abundant fungi.

|                       |                             |
|-----------------------|-----------------------------|
|                       | Cladosporium <sup>++</sup>  |
|                       | Sporobolomyces <sup>+</sup> |
| Alternaria            | Erysiphe                    |
| Basidiospores – brown | Fusiform ascospores         |
| hyaline               | "Penicillium"               |
| yellow                | Tilletiopsis                |
| Botrytis              | Ustilago                    |

The variation in counts between the city and country sites in 1954 may be explained by the difference in the proximity and strength of the sources. The height of the spore traps above the ground may also have influenced the counts, the country trap being 2 metres and the city trap 16 metres above ground level. Gregory & Hirst (1957) found the spore concentration of the 12 commonest groups at 24 metres totalled 82 per cent of that at 2 metres.

Variation between counts at the city site in 1954 and 1955 may be attributed to seasonal differences. The summer months *in general* being cold and wet in 1954 and warm and dry in 1955.

The counts for different spore types showed a marked variation, ranging from an average of 1 spore per cubic metre of air for *Chaetomium* to 5,710 per cubic metre for *Cladosporium*. On the other hand the variation between the counts

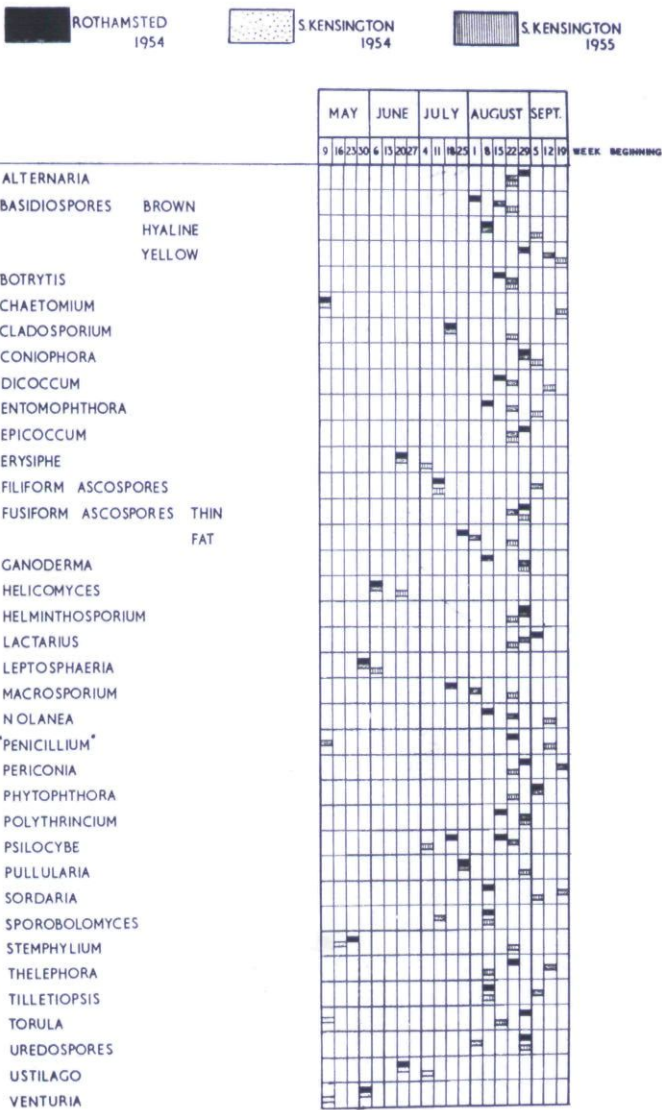
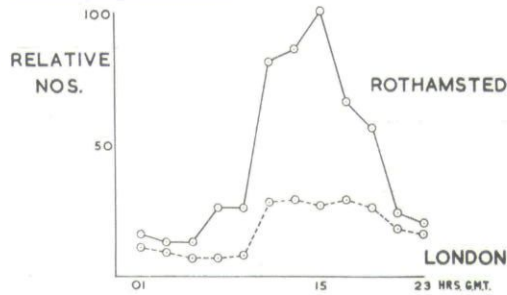
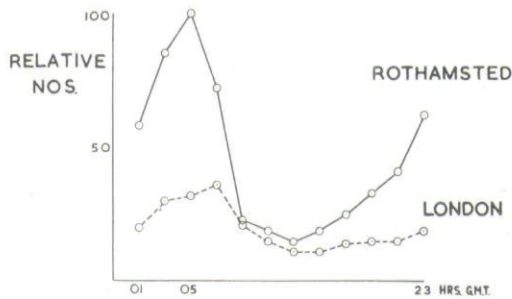


Fig. 9.

Dates of the highest weekly average spore counts.

CLADOSPORIUMSPOROBOLOMYCES*Fig. 10.*

Diurnal periodicity curves based on data from May to September 1954.

in two different localities and in two different years for any particular spore type was never greater than tenfold.

Most spore types have a characteristic seasonal incidence and *Fig. 9* summarises the dates of the highest weekly average spore counts for the three surveys.

Besides this seasonal periodicity many types of fungus spores exhibit a diurnal periodicity; some are most abundant during the day e.g. *Cladosporium* (*Fig. 10 a*), while others are most abundant on the slides during the night. e.g. *Sporobolomyces* (*Fig. 10 b*). It will be readily appreciated that a single ten minute exposure of a culture plate in the course of the day is not likely to give a representative picture of the incidence of fungus spores.

TABLE 3  
*Temperatures at which highest counts of spores recorded.*

| °F    | °C        | Spore Category                                                                                                                                           |
|-------|-----------|----------------------------------------------------------------------------------------------------------------------------------------------------------|
| 40-44 | 4.4- 6.7  | Leptosphaeria.                                                                                                                                           |
| 45-49 | 7.2- 9.4  | Venturia.                                                                                                                                                |
| 50-54 | 10.0-12.2 | Nolanea; "Penicillium".                                                                                                                                  |
| 55-59 | 12.8-15.0 | Yellow basidiospores.                                                                                                                                    |
| 60-64 | 15.6-17.8 | Fusiform (thin) ascospores;<br>Sporobolomyces; Tilletiopsis.                                                                                             |
| 65-69 | 18.3-20.6 | Coniophora; Entomophthora;<br>Fusiform (fat) ascospores; Lactarius.                                                                                      |
| 70-74 | 21.1-23.3 | Cladosporium; Diccoccum; Erysiphe;<br>Helicomycetes Periconia; Ustilago.                                                                                 |
| 75-79 | 23.9-26.1 | Alternaria; Chaetomium; Filiform asco-<br>spores; Ganoderma; Phytophthora; Poly-<br>thrincium; Pullularia; Sordaria;<br>Thelephora; Torula; uredospores. |
| 80-84 | 26.7-28.9 | Brown basidiospores; Yellow basidiospores;<br>Botrytis; Epicoccum; Fusiform (thin) asco-<br>spores; Helminthosporium; Macrosporium,<br>Psilocybe.        |
| 85-89 | 29.4-31.7 | Hyaline basidiospores.                                                                                                                                   |

On the basis of the diurnal periodicities of the meteorological factors spores which require high humidity conditions for their production and dispersion would be encountered in the early morning or during rain, while spores which have no special mechanisms to aid dispersion would be dislodged in the afternoon.

In many Ascomycetes free water is required for the expansion of the ascospores: Hymenomycete spores are typically discharged by the drop secretion method (Buller, 1933) and these are the fungi which are found in greater concentrations during the night.

As the dew evaporates, the drying of the leaf surfaces during the day increases the powderiness of the conidia of many of the Fungi Imperfecti; the uredospores of rusts and the chlamydospores of *Ustilago*. These are the fungi with maximum counts of spores during the day.

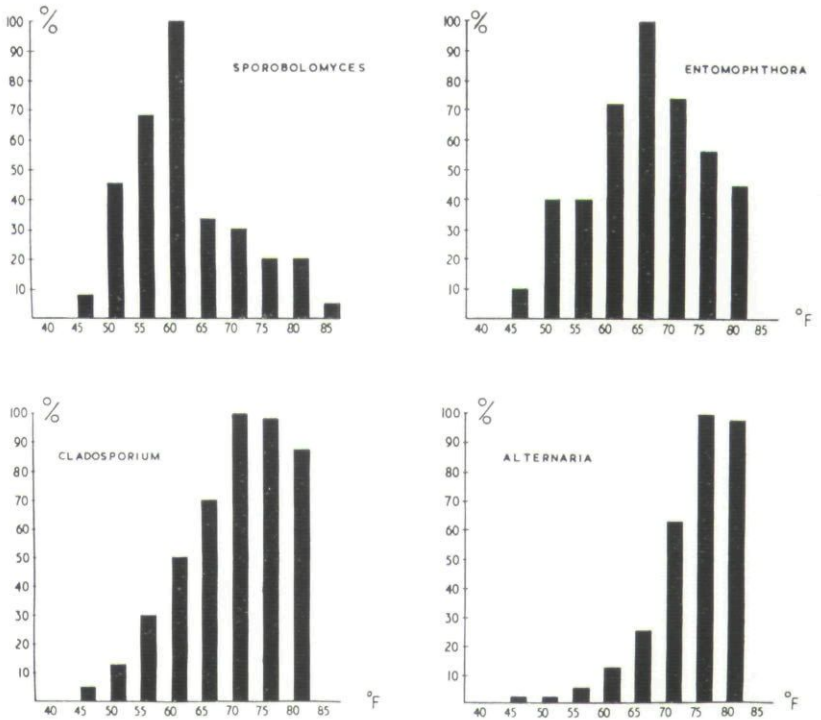


Fig. 11.

Effect of temperature on the spore counts, London,  
May to September, 1955.

In a similar manner rain affects the spore counts and fungi such as those listed below have significantly higher spore counts when there is *no rain*.

|                  |               |
|------------------|---------------|
| Alternaria       | Periconia     |
| Cladosporium     | Polythrincium |
| Epicoccum        | Torula        |
| Erysiphe         | Uredospores   |
| Helminthosporium | Ustilago      |
| Macrosporium     |               |

Certain ascospores on the other hand give significantly higher spore counts *during rain*.

The time of day when rain falls will also affect the spore

counts. Taking as an example, *Cladosporium* the spores of which reach maximum concentration in the air in the afternoons, it was found that although rain all day, or rain in the afternoon only, significantly reduced the *Cladosporium* count, rain in the morning only did not affect it significantly.

Table 3 lists the temperatures at which each spore type was most abundant in the air. With the accumulated data, bar graphs were constructed showing the effect of temperature on the spore counts. (*Fig. 11*).

The correlations found between the numbers of spores or pollen grains and the corresponding meteorological data give some indication of the conditions which favour spore and pollen production, but the long term effects of these meteorological conditions were not studied here. It is necessary to bear in mind that the microclimate of leaf surfaces and of the layers of air close to the ground may vary considerably from that at two metres (Sutton, 1953): further, the occurrence of many fungi is known to depend on the physiological state of the host plant (Last, 1955).

Other airborne particles which may form potential hazards to sensitive patients include mycelial fragments, algal groups and insect hairs and scales, all of which are most abundant in the air in late August and give their highest counts in dry weather.

#### SUMMARY

A quantitative and qualitative survey was made of particles of the size range 3 to 40 microns which were airborne during the summer months May to September, in London, England, and in a country district 22 miles from London. Particular emphasis is placed on the fungus spore component of the catch and this, together with other organic particles e.g. pollen grains, algae, insect fragments etc. was found to exhibit both a seasonal and a diurnal periodicity of occurrence in the air. The findings for inorganic particles are briefly mentioned. Although many pollen grains and fungus spores were significantly correlated with individual meteorological factors it is

obvious that the annual trend was greater than the immediate meteorological effect.

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