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# Vertical Profiles of Spore Concentrations Near the Ground

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The changes in air-spora concentration along a vertical line from the ground level were followed up to 5m. Rotorod samplers were run simultaneously for an hour in any single test at six heights, viz., 0.05, 1, 2, 3, 4, and 5 m. Series of tests were done on three different occasions. In two series, seven tests, each at 4-hourly intervals and in another, thirteen tests, each at 2-hourly intervals were done over a 24 hr period.

The observed patterns in vertical profiles of spore concentration were described with the help of a few selected spore types. Spore concentrations in general decreased with the increase in height from ground level. The total air-spora always showed such a trend, but the individual spore types behaved thus only during the times of rapid spore liberation. The rate of decline in concentration was not of the same order with all the spore types even in a single test; this behaviour was related to the difference in their terminal velocities. The day-spora types (*Oidium*, *Nigrospora*, *Alternaria*, *Periconia*) showed a rather less rapid decrease whereas the night-spora types (*Fusarium*, *Pleospora*, 'ascospores') as well as the day-spora ones ('uredospores', *Pithomyces*, *Curvularia*, *Xanthium*) which exhibited clumping decreased rather rapidly. The degree of the slope of the gradient for an individual spore type as well as total air-spora varied, as indicated by the values of the regression coefficient, *b*, according to the time of day and consequently with the magnitude of atmospheric turbulence.

**Key Words: Aerobiology, Air-spora, Spore dissemination, Vertical gradients**

## Introduction

When a spore cloud is generated from a source, the spores get diffused both horizontally and vertically. In respect of vertical gradients, the earlier workers, starting with the pioneer work of Stakman et al. (1923), collected spores on sticky slides exposed from aeroplanes at different altitudes from 60 m above ground level. These data, together with those obtained by the use of volumetric traps adopted for use from air

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craft, showed that spore concentrations generally decrease with height, and the decrease is normally logarithmic, although the picture varies in different conditions of air stability (Hirst & Hurst 1967). But very little is known of the norms of vertical spore concentration changes in the layers nearer the ground (Gregory 1954, Last 1955). In recent years, information on vertical spore concentrations within and above crops has been provided by Sreeramulu and Ramalingam (1965), Eversmeyer et al. (1973), Subba Reddi and Ramakrishna (1978), and Subba Reddi et al. (1978). However, no data appear to be available for other situations excepting those of Janaki Bai and Subba Reddi (1976). Therefore, with the aim of providing a picture as complete as possible of the vertical spore concentration changes near the ground, a number of air sampling tests were performed under different environmental regimes, in each test measurements being taken of spore concentrations at six positions up to 5 m above ground level along a vertical line among natural vegetation. The results obtained are presented here.

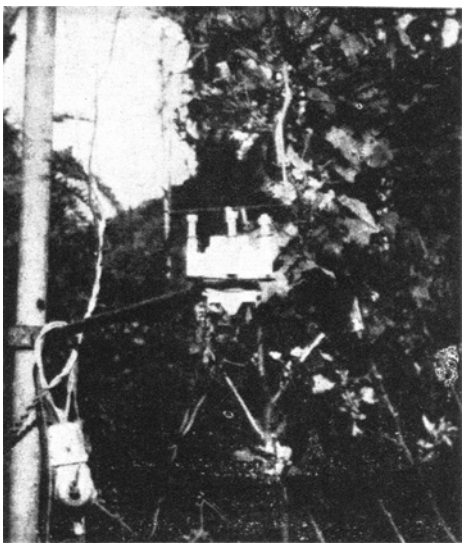


**Figure 1** Photograph showing a part of the air sampling system: G.I. Pipe and horizontal iron rod with Rotorod sampler in its socket.

## Materials and Methods

Rotorod samplers of Perkins' (1957) model (figure 1) were used to catch the spores. These are highly suitable for short period sampling up to 2 hr and their efficiency is largely independent of wind speed. While working, the spores are impacted on to the leading sides of the upright rotating arms of the 'U'-shaped brass rod furnished with removable, vaseline-coated strip of cellotape suitably attached. Spores of the size range from 150 to 2.5 $\mu$m are caught with reasonable accuracy (Batchelder 1977).

Six Rotorod samplers were got fabricated with a screw device on the one cm long axis to keep it firmly on the motor shaft. Each Rotorod was mounted on a HMV motor of 12 v capacity. The motors, after connecting to the step-down transformer, were run on AC current. Each motor with the Rotorod mounted, rotated at 2200 rpm (determined with the help of Stroboscope).

In order to operate the six traps simultaneously along a vertical line with each unit positioned at the desired height, a five-meter length GI pipe was taken and six half-meter iron rods with a socket to hold the sampling unit at one end were fixed horizontally i.e., at right angles to the pipe. The air sampling units were fixed in the sockets and each connected to the step-down transformer on parallel way.

A series of tests were done on 26–27 November 1977, 1–2 March 1978 and 11–12 November 1978. On each of the first two occasions, 7 tests, each at 4-hourly intervals were conducted over a 24-hr period; on the third, 13 tests, each at 2-hourly intervals, were done. The first two series of tests were done in the premises of Botany Department in the Andhra University Campus, Waltair. The area was occupied by good vegetation, comprising herbs (including grasses), shrubs

and tress, thus providing good substratum especially in the form of dead and decaying vegetable matter for the growth of fungi. The other series of tests were done in an area occupied by *Xanthium*, *Mimosa* and grasses near the Krishna Poultries by the side of the NH5 at a distance of 2.5 km from the University Campus. In each test, air sampling was done continuously for one-hour period.

The sticky cellotape strips on the Rotorod arms exposed in each test, were dismounted on to the clean, labelled slides using glycerine jelly as the mountant. The strips were later scanned across the trace on a width of 180 $\mu$m at 3 mm apart. The spores thus counted, were expressed as number per cubic meter air.

In constructing the vertical concentration profiles, the spore concentrations were expressed as log $(n+1)$ and plotted against the log of height. This method of presentation accommodates large numbers without losing sensitivity to small ones and was chosen after Johnson and Penman (1951). The data were fed to IBM computer 1130 for regression analysis of log $X$ (spore concentration) on log $Y$ (height a.g. l.) utilising the double log exponential model. The coefficient, $b$, was taken to compare the gradients observed of the different spore types.

## Results

Of the several different kinds of plant spores for which separate counts were taken, only a few types like the pollen of *Xanthium*, conidia of *Fusarium*, *Periconia*, *Corynespora*, *Nigrospora*, *Curvularia*, *Alternaria*, *Pithomyces*, *Oidium*, ascospores of *Pleospora*, the 'ascospores' and 'uredospores' as groups were selected for illustration. These are the types that occurred in considerable numbers and exhibited more or less distinct periodicity in their incidence in a 24 hr cycle. Further, the types *Fusarium*, *Pleospora* and 'ascospores' represent the wet-spora elements whereas the others constitute the dry-spora.

The observed concentrations at different heights in a test were summed up and these are presented in tables 1a, 1b and 1c, indicating the rhythmicity in the occurrence of each of the selected spore type in a 24 hr cycle. The profiles of the individual spore types as well as total air-spora observed in each test of each series are presented in figures 2 and 3. In each series of tests, the counts obtained at the corresponding heights were totalled and the summation profiles constructed for each of the selected spore type as well as total air-spora are given in (figures 4–6)

In general, spore concentration declined with increase in height from the ground level. The concentrations were greater at the lowest position than at heights; this tendency is mostly noticeable in the periods of most rapid spore liberation. However, with *Oidium* the conidial concentration at the lowest level was slightly lower than at the height immediately above. The ratios of spore concentrations (calculated by division of the spore concentration at the upper elevation by that at the lower elevation) at different sampling heights which indicate the rate of their decrease or increase from height to height were not the same for all spore types as well as the total air-spora even in the same test. Furthermore, the ratios at the different successive heights were not of the similar order for a type in a particular test.

The observed shape of the profile of each of the individual spore types is either smooth or broken. The smooth profile shows a progressive decreasing trend in the levels of spore concentrations corresponding with the increase in height above the ground level whereas the other does not show such trend and the concentrations may be intermittently increasing or decreasing. The profiles of the individual spore types obtained in the periods of their rapid liberation, are

always smooth while those noticed at the other times broken or eroded. The total air-spora profiles as well as the summation ones are always smooth. As already stated the linear regression of log $X$ on log $Y$ was computed using the regression equation: log $X$=log $a$+$b$ log $Y$ following Gregory (1973) to compare in a better way the vertical gradients of different spore types and of individual spore types as well as total air-spora at different times of the day. Table 2a gives the values of $b$ for the summation profiles of each of the selected spore types as well as total air-spora and table 2b the values of $b$ for the total air-spora obtained at different times in the 24 hr period; computed $R^2$ and $F$ values are also included in the tables as combined indicators of goodness of fit and significance of slopes. From these $b$ values, it can be said that the gradients of *Fusarium*, *Pleospora*, *Pithomyces*, *Curvularia*, *Xanthium*, 'uredospores' as well as total air-spora are rather steep; those of other spore types tended to be less steep.

**Table 1a** *Sums of spore concentrations (No./m³ of air) at all heights in different tests conducted at different times on 26–27 November 1977*

| Spore type | Time (hr) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0900–1000 | 1300–1400 | 1700–1800 | 2100–2200 | 0100–0200 | 0600–0700* | 0900–1000 |
| *Pithomyces* | 410 | 270 | 2060 | 0 | 0 | 340 | 660 |
| 'Ascospores' | 30 | 30 | 950 | 2140 | 5390 | 360 | 240 |
| *Fusarium* | 10 | 0 | 180 | 260 | 1930 | 1630 | 0 |
| *Nigrospora* | 1580 | 170 | 10 | 30 | 0 | 0 | 440 |
| *Alternaria* | 1150 | 260 | 190 | 20 | 20 | 70 | 1640 |

*Due to power breakdown there was a shift by an hour in the scheduled time of conducting the test

**Table 1b** *Sums of spore concentrations (No./m³ of air) at all heights in different tests conducted at different times on 1–2 March 1978*

| Spore type | Time (hr) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0900–1000 | 1300–1400 | 1700–1800 | 2100–2200 | 0100–0200 | 0500–0600 | 0900–1000 |
| *Curvularia* | 920 | 1150 | 900 | 190 | 260 | 90 | 230 |
| *Oidium* | 1890 | 760 | 70 | 40 | 20 | 0 | 120 |
| 'Uredospores' | 570 | 930 | 600 | 170 | 140 | 30 | 160 |
| *Periconia* | 1890 | 1280 | 1210 | 840 | 1090 | 410 | 700 |
| *Pithomyces* | 1640 | 830 | 500 | 160 | 240 | 70 | 50 |
| *Nigrospora* | 410 | 160 | 190 | 20 | 20 | 30 | 150 |

**Table 1c** *Sums of spore concentrations (No./m³ of air) at all heights in different tests conducted at different times on 11-12 November 1978*

| Spore type | Time (hr) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1300-1400 | 1500-1600 | 1700-1800 | 1900-2000 | 2100-2200 | 2300-2400 | 0100-0200 | 0300-0400 | 0530-* 0630 | 0730-* 0830 | 0900-1000 | 1130-* 1230 | 1300-1400 |
| *Xanthium* | 260 | 180 | 100 | 30 | 20 | 0 | 0 | 0 | 0 | 4080 | 1860 | 620 | 170 |
| *Corynespora* | 260 | 290 | 70 | 0 | 0 | 0 | 0 | 0 | 0 | 1970 | 2340 | 850 | 280 |
| *Periconia* | 760 | 740 | 370 | 350 | 100 | 150 | 80 | 70 | 80 | 1050 | 1940 | 1840 | 840 |
| *Pleospora* | 0 | 0 | 0 | 0 | 0 | 0 | 60 | 2590 | 1360 | 70 | 0 | 0 | 0 |
| *Fusarium* | 0 | 0 | 0 | 10 | 300 | 400 | 940 | 1260 | 430 | 0 | 0 | 0 | 0 |

*Due to power breakdown there was a shift by half an hour in the scheduled time of conducting the tests.

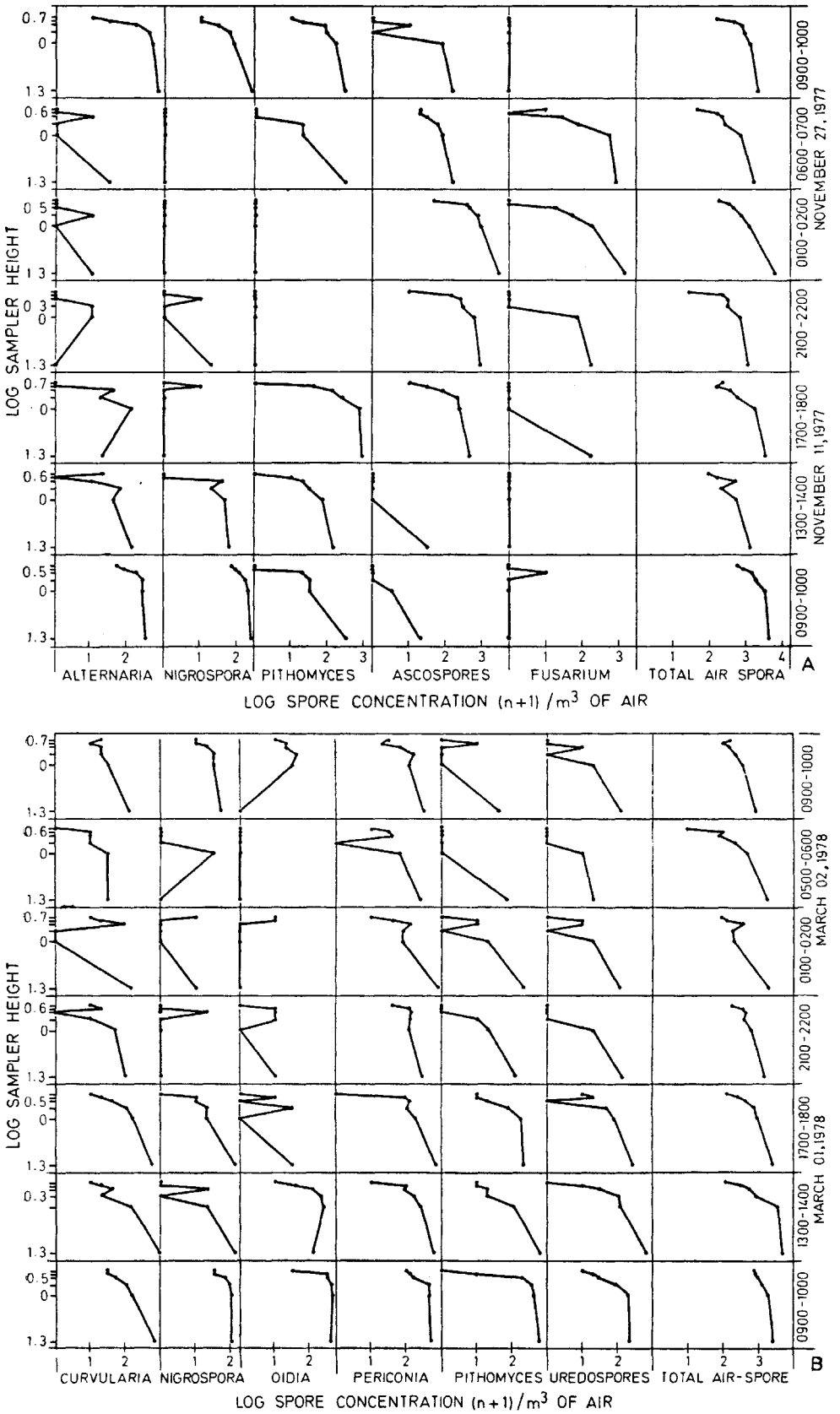



**Figure 2** Profiles of vertical concentrations of different spore types as well as total air-spora observed at different times during a 24 hour period on 26–27/11/1977 (**A**) and on 1–2/3/1978 (**B**)

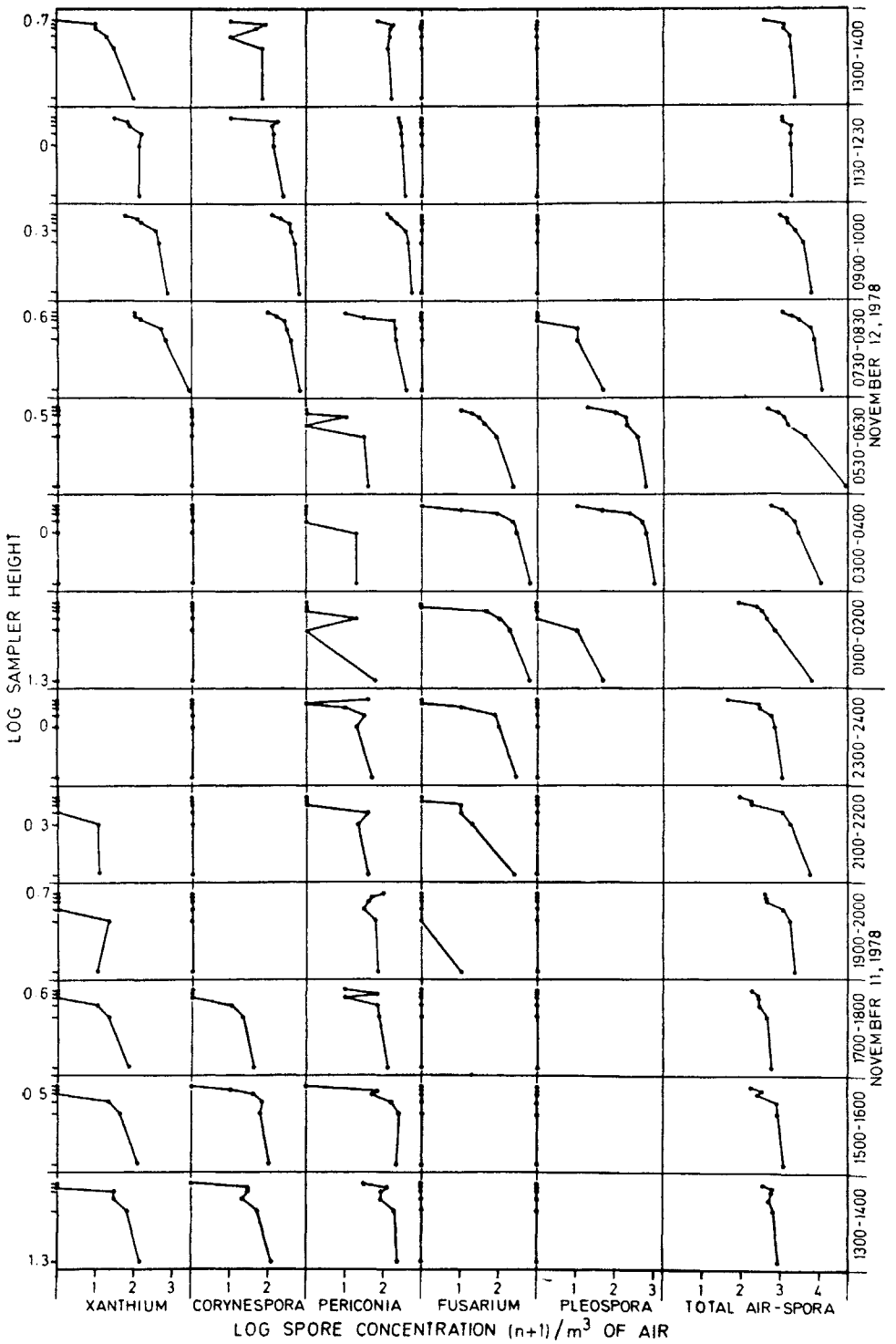



**Figure 3** Profiles of vertical concentrations of different spore types as well as total air-spora observed at different times during a 24 hour period on 11–12/11/1978

The total air-spora gradients of the day time are in general less steep than of the night time.

## Discussion

The cause of vertical diffusion of microbial spore cloud in the lower layers of the atmosphere is the frictional turbulence. Under a stable state of diffusion by eddies, the cloud concentration decreases logarithmically with increase in height from the ground level if the source of the air-borne spore cloud lies nearer the ground layer (Gregory 1973). So to speak, the logarithm of spore concentration should give a straight line when plotted against the logarithm of the height. This expected linear relationship was not always realised as is evident from the nature of profiles in figures 2 and 3, and from the values of $R^2$ and $F$ in tables 2a and 2b. Factors like spore source proximity, continuity and height together with the climatic conditions could greatly influence the profiles. Unless the sources are identified with definiteness, no reasonable explanation for the observed deviations from the expected linear relationship could be offered. As already indicated most of the spores were from saprophytic fungi growing on dead and decaying vegetable matter, and as such identification of their sources was not

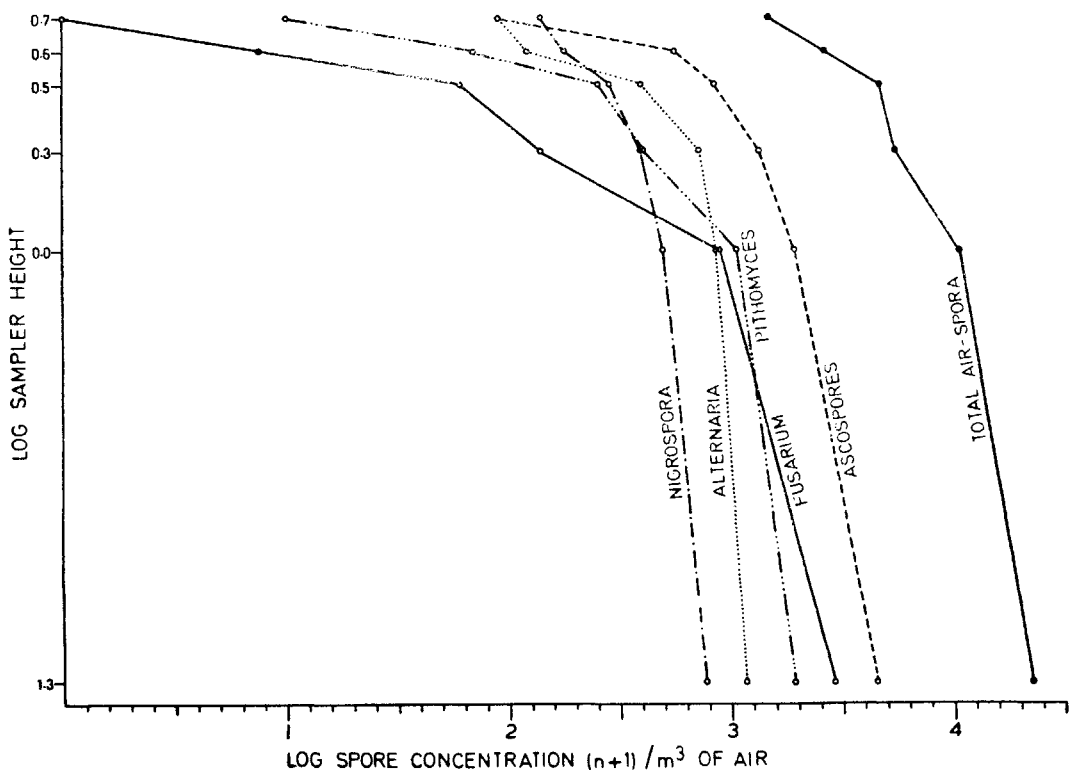
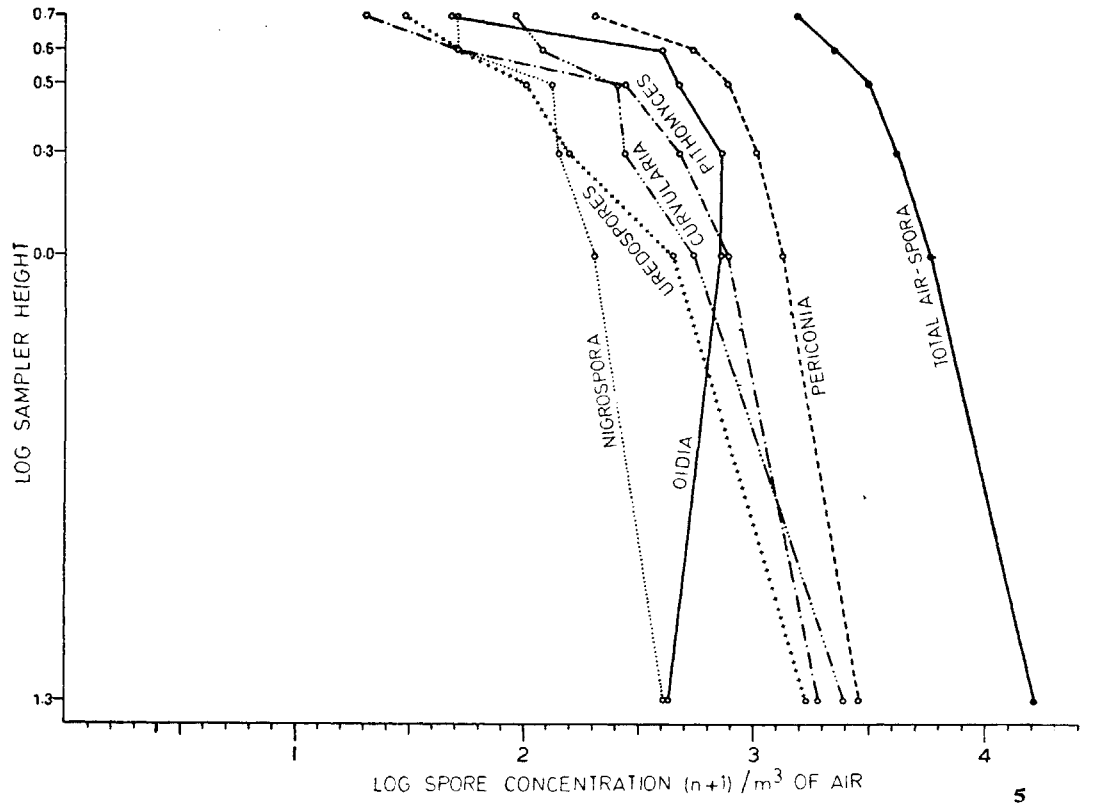



**Figure 4** Summation profiles of vertical concentrations of different spore types as well as total air-spora of 26–27/11/1977 series of tests



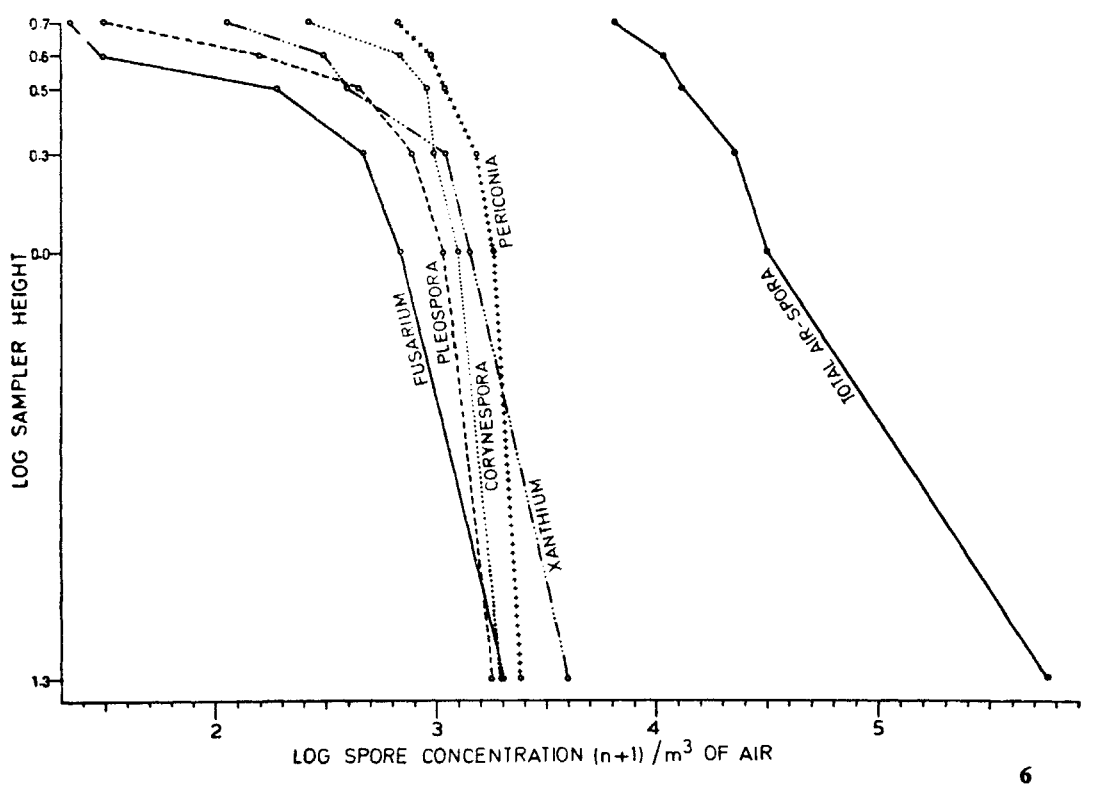




**Figure 5 & 6** Summation profiles of vertical concentrations of different spore types as well as total air-spora. **5**, 1–2/3/1978; **6**, 11–12/11/1978 series of tests

**Table 2a** *Values of regression coefficient, b, for the summation profile of each selected spore type as well as total air-spora*

| | *b* *SE* | $R^2$ | Calculated *F*-Value |
|---|---|---|---|
| 26–27 November 1977 | | | |
| *Pithomyces* | 0.85±0.36 | 0.59 | 5.64 |
| 'Ascospores' | 0.61±0.24 | 0.62 | 6.64 |
| *Fusarium* | 1.40±0.48 | 0.68 | 8.38+ |
| *Nigrospora* | 0.32±0.09 | 0.77 | 13.15* |
| *Alternaria* | 0.46±0.21 | 0.55 | 4.95 |
| Total air-spora | 0.52±0.12 | 0.82 | 17.94* |
| 1–2 March 1978 | | | |
| *Curvularia* | 0.67±0.08 | 0.94 | 61.36* |
| *Oidium* | 0.85±0.17 | 0.10 | 0.43 |
| 'Uredospores' | 0.85±0.17 | 0.86 | 24.02* |
| *Periconia* | 0.45±0.14 | 0.72 | 10.29* |
| *Pithomyces* | 0.76±0.27 | 0.67 | 8.29* |
| *Nigrospora* | 0.42±0.11 | 0.79 | 14.64* |
| Total air-spora | 0.47±0.07 | 0.93 | 50.24* |
| 11–12 November 1978 | | | |
| *Fusarium* | 0.92±0.35 | 0.64 | 7.08 |
| *Pleospora* | 0.63±0.30 | 0.53 | 4.44 |
| *Periconia* | 0.23±0.07 | 0.74 | 11.28* |
| *Corynespora* | 0.31±0.13 | 0.60 | 5.88 |
| *Xanthium* | 0.66±0.19 | 0.76 | 12.46* |
| Total air-spora | 0.93±0.04 | 0.99 | 535.74* |

F (O.05) 7.71, 1, 4
*indicates the significant F—value

**Table 2b** *Values of regression coefficient, b, for total air-spora caught at different times in different 24 hr periods*

| | *b* *SE* | $R^2$ | Calculated *F*-value |
|---|---|---|---|
| 26–27 November 1977 | | | |
| 9-10 hr | 0.38±0·12 | 0.71 | 10.02* |
| 13-14 | 0.46±0.16 | 0.69 | 8·81* |
| 17-18 | 0.65±0.15 | 0.82 | 18.59* |
| 21-22 | 0.55±0.26 | 0.53 | 4.49* |
| 1-2 | 0.69±0.09 | 0.94 | 58.51* |
| 6-7 | 0.63±0.17 | 0.76 | 12.99* |
| 9-10 | 0.43±0.17 | 0.62 | 6.42 |
| 1–2 March 1978 | | | |
| 9-10 hr | 0.28±0.05 | 0.88 | 28.12* |
| 13-14 | 0.66±0.15 | 0.83 | 19.65* |
| 17-18 | 0.55±0.13 | 0.81 | 16.54* |
| 21-22 | 0.37±0.08 | 0.86 | 23.99* |
| 1-2 | 0.58±0.12 | 0.84 | 21.42* |
| 5-6 | 0.88±0.26 | 0.74 | 11.09* |
| 9-10 | 0.42±0.08 | 0.88 | 29.64* |
| 11–12 November 1978 | | | |
| 13-14 hr | 0.14±0.06 | 0.57 | 5.25 |
| 15-16 | 0.38±0.15 | 0.61 | 6.26 |
| 17-18 | 0.20±0.05 | 0.80 | 15.81* |
| 19-20 | 0.40±0.13 | 0.71 | 9.70* |
| 21-22 | 0.85±0.21 | 0.81 | 16.88* |
| 23-24 | 0.51±0.23 | 0.56 | 5.11 |
| 1-2 | 0.82±0.09 | 0.95 | 78.15* |
| 3-4 | 0.54±0.08 | 0.91 | 40.98* |
| 5-6 | 0.97±0.06 | 0.98 | 230.22* |
| 73-830 | 0.43±0.15 | 0.67 | 8.01* |
| 9-10 | 0.36±0.08 | 0.83 | 19.84* |
| 1130-1230 | 0.13±0.06 | 0.53 | 4.50 |
| 13-14 | 0.25±0.14 | 0.44 | 3.14 |

*F* (0.05) 7.71 1, 4
*indicate the significant F-value

possible. It is further evident from the profiles of individual spore types (figures 2 and 3) that regular decrease in spore levels with increase in height would occur mainly during the times of most rapid spore liberation; at other times such a trend would not exist. In other words, when the source got depleted due to horizontal and vertical dispersion, such a decreasing trend would not be realised. A similar conclusion was made by Janaki Bai and Subba Reddi (1976) who mapped the vertical profiles of *Cyperus rotundus* pollen. However, the total air-spora as well as the summed up concentrations of the individual spore types showed a progressive decreasing trend up to the maximum height (5 m) studied now. This may be so because biological factors in a circadian cycle put vastly differing numbers of organisms into the air at different times and the cumulative vertical concentrations experience a decreasing trend with increasing height above ground level.

The observed result that the ratios of spore concentration at a particular height in a particular test are not the same for the different spore types, show that the decrease in concentration levels was not of the same order for all the spore types. This might be true because the different spore types vary in their terminal velocities. It was also observed that the ratios of concentrations of particular spore types at successive heights in a particular test were not the same. Apparently even for the same spore type, the change in spore concentration levels might not be of the same magnitude. Obviously this behaviour could be tied up with the temperature gradient. These observations are in conformity with those of Last (1955) and Eversmeyer et al. (1973).

The magnitude of atmospheric turbulence depends on vertical temperature gradient and consequently varies according to the time of day. It can, therefore, be expected that the rate of decrease in spore concentration levels or in other words the slope of the profile vary accordingly. Low turbulent conditions usually exist during night. During daylight superadiabatic lapse conditions normally develop after sunrise and as time advances, conditions change from superadiabatic to adiabatic and by 14 hr the turbulence would be at its maximum. Accordingly, the rate of decrease in spore concentration levels would vary by night and day. This tendency is actually relised. Types like *Fusarium*, *Pleospora* and 'ascospores' are usually liberated under moist nocturnal conditions; they were recorded mainly during 21-07 hr (tables 1a and 1c). As a result, their numbers decreased rather rapidly as indicated by *b* values (table 2a) of the summation profiles. Such behaviour was also noticed with 'uredospores', *Pithomyces*, *Curvularia* and *Xanthium* which are the constituents of the dry-spora. With these types, clumping was commonly observed while scanning and as such the dispersal units were not exclusively single spores. Consequently, the terminal velocities of these dispersal units increased. This accounts for the rapid decrease in spore concentration of these dry-spora types. In contrast to the aforesaid dry-spora types, the gradient obtained for the conidia of *Oidium*, *Nigrospora*, *Alternaria* and *Periconia* indicate rather less rapid decrease in their concentration levels.

The gradient *b*, of the total air-spora (table 2b) of different times reveal that the rate of decrease in concentration levels is rapid in tests done during night than in those of day. The prevailing temperatures at the three heights (0.05, 2 and 4 m) and relative humidity as well as wind speed at 2 m height recorded for the series of tests in the *Xanthium* field and given in table 3 indicate the relationship between the vertical temperature gradient and the slope of the vertical spore concentration profiles (see figure 3 and table 3).

**Table 3** *Particulars of times of air-sampling and weather of the tests conducted on 11–12 November 1978*

| Time of air sampling (h) | | Temperature (°C) at | | | Relative humidity (%) at 2 m | Wind speed (km/hr) at 2 m |
|---|---|---|---|---|---|---|
| Start | Finish | 0.05 m | 2 m | 4 m | | |
| 1300 | 1400 | 38.0-38.5 | 33.8-33.0 | 30.5-30.8 | 66-63 | 2.82 |
| 1500 | 1600 | 35.0-30.5 | 30.5-28.0 | 29.0-28.5 | 67-83 | 3.04 |
| 1700 | 1800 | 26.5-26.5 | 27.5-27.2 | 27.5-27.0 | 86-92 | 1.94 |
| 1900 | 2000 | 27.5-25.5 | 27.0-27.0 | 27.0-27.0 | 94-96 | 1.94 |
| 2100 | 2200 | 25.0-24.5 | 26.3-25.6 | 25.3-25.7 | 100-100 | 0.08 |
| 2300 | 2400 | 24.0-23.7 | 25.0-24.5 | 25.0-24.3 | 82-100 | 0 |
| 0100 | 0200 | 23.5-23.2 | 25.0-24.3 | 25.0-24.3 | 100-100 | 0 |
| 0300 | 0400 | 22.8-22.5 | 23.8-23.2 | 23.9-23.1 | 100-95 | 0 |
| 0530 | 0630 | 22.6-22.6 | 22.9-23.0 | 22.7-23.0 | 100-100 | 0 |
| 0730 | 0830 | 28.2-30.2 | 27.5-29.2 | 26.0-28.2 | 76-72 | 0.62 |
| 0900 | 1000 | 29.5-35.3 | 31.2-31.3 | 30.5-31.2 | 55-62 | 1.04 |
| 1130 | 1230 | 33.5.34.5 | 30.8-30.0 | 31.3-30,5 | 59-76 | 2.74 |
| 1300 | 1400 | 35.3-34.0 | 30.0-30.5 | 30.0-30.0 | 68-74 | 3.15 |

With these data, it does not seem justifiable to comment on the heights at which an air sampling device has to be installed in order to obtain a reasonably typical sample of the air-spora of a region. However, the data show a rapid falling off at only a short vertical distance in the atmospheric concentrations of spores. This suggests that the catches obtained over roof-tops would be rather underestimates and do not suggest nose level concentrations of plant spores with sources nearer to the ground.

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## References


Batchelder G L 1977 Sampling characteristics of the rotorod, rotoslide and andersen machines for atmospheric pollen and spores; *Ann. Allergy* **39** 18–27

Eversmeyer M G, Kramer C L and Burleigh J R 1973 Vertical spore concentrations of three wheat pathogens above a wheat field; *Phytopathology* **63** 211–218

Gregory P H 1954 The construction and use of a portable volumetric spore trap; *Trans. Br. mycol. Soc.* **37** 390–404

——1973 *The Microbiology of the Atmosphere* 2nd edn (Leonard Hill) Chapters XII and XVI

Hirst J M and Hurst G W 1967 Long distance transport pp. 307 344: in *Airborne Microbes* eds. Gregory & Monteith (Cambridge Univ. Press)

Janaki Bai A and Subba Reddi C 1976 Pollen productivity and pollen incidence in *Cyperus rotundus* Linn.; *Botanique* (Nagpur) **7** 107–110

Johnson C G and Penman H L 1951 Relationship of aphid density to altitude; *Nature (Lond.)* **168** 337

Last F T 1955 The spore content of air within and above mildew infected cereal crops; *Trans. Br. mycol. Soc.* **38** 453–464

Perking W A 1957 The Rotorod sampler *2nd Semiannuaal Rept. Aerosol Lab*; Deptt. of Chemistry & Chem. Engg., Stanford Univ. CML **186** 66 pp.

Sreeramulu T and Ramalingam A 1965 Vertical gradients in air-borne spores three meters above ground level; *Proc. Combd. 51st and 52nd Indian Sci. Congr.* Delhi pt. III Bot. Abst. **62** 324

Stakman E C, Henry A W, Curran G C and Christopher W N 1923 Spores in the upper air; *J. agric. Res.* **24** 599–606

Subba Reddi C and Ramakrishna V 1978 Vertical profiles of spore concentrations within and above a *Sorghum* crop; *Phytopath. Z.* **39** 35–40

——, —— and Sreeramulu T 1978 Vertical profiles of spore concentrations within and above a sugarcane crop; *Proc. Indian Acad. Sci.* **B87** 309–317