THE RELATIONSHIP BETWEEN POLLEN RAIN, VEGETATION, CLIMATE, METEOROLOGICAL FACTORS AND LAND-USE IN THE PWV, TRANSVAAL

AN [illegible]AD[illegible]AN

Submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in the Department of Botany, University of the Witwatersrand,

Ma[illegible] 1991.

I, Ann Cadman, do hereby declare that the thesis entitled

THE RELATIONSHIP BETWEEN POLLEN RAIN, VEGETATION, CLIMATE, METEOROLOGICAL FACTORS AND LAND-USE IN THE PWV, TRANSVAAL

is my own work, and that it has not been submitted for degree purposes in whole or in part to any other university. To my knowledge, all sources used in this study have been indicated and acknowledged by means of complete references.

A. CADMAN

March, 1991.

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Abstract

A two-year analysis of pollen rain was conducted in the Pretoria-Witwatersrand-Vereeniging district of the Transvaal, South Africa. Poaceae was the major component of the pollen assemblage, comprising 52% regionally. Of the total pollen count 58.8% was non-seasonal and present throughout the year. During the analysis it became apparent that fungal spores dominated the atmospheric content, accounting for 94% of total airspora, considered here to include pollen and fungal spores.

In relating airspora to meteorological factors, Poaceae pollen was associated most closely with temperature. High spring rain was related to high summer Poaceae pollen. There was considerable variation in the response of Poaceae pollen to meteorological factors between Johannesburg and Pretoria. This variability was attributed to differences in climatic regions of the cities.

Fungal spores showed a finer response than Poaceae pollen to conditions in the immediate vicinity of the sampling stations.

Atmospheric pollen did not accurately reflect vegetation in the immediate vicinity of samplers, if the total pollen assemblage was considered. Only Poaceae pollen and entomophilous tree pollen were correlated with vegetation. Anemophilous trees were over-represented, as were entomophilous non-arboreal taxa. Atmospheric samples did

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Chapter 1

Rationale and Methodology

1.1 Introduction

Palynology is useful in the interpretation of various palaeontological and archaeological problems (Birks & Birks 1980, Traverse 1988). Deductions made from a fossil pollen assemblage are determined by the factors that produced that assemblage. Such deductions are based on observations made of relationships between biotic and abiotic factors that influence present day pollen deposition. However, the exact relationship that modern pollen rain has with extant vegetation, climatic factors and land-use is poorly understood. There have been no studies of the quantitative interaction of these parameters in South Africa. The elegant studies of Coetzee (1967, 1978), Scott (1982, 1986) and van Zinderen Bakker (1976, 1982) concentrated on qualitative work. Scott (1989a, 1989b) and Scott and Thackeray (1987) applied factor analysis to Quaternary pollen sequences, and Hawke and Meadows (1989) briefly examined meteorological determinants of the airspora during a five-week winter period in Cape Town, but this study is the first to provide a detailed account of some of the quantitative aspects of pollen rain in the South African environment.

Many inter-related factors determine the composition of pollen rain. These factors are broadly divided into biotic and abiotic factors.

Biotic factors

In the first instance, the species present in both local and regional vegetation determine the composition of the atmospheric pollen spectrum. Pollen production controls the quantity available for dispersal, while features of the canopy, eg height and density, limit dispersal into the atmosphere.

Morphology of the pollen grain is important, where shape and size of the grain affect buoyancy. Physical attributes of the anthers are also pertinent, eg size, method of dehiscence and position in the inflorescence. These characteristics in turn determine the exposure of the anthers to the elements.

Abiotic factors

Atmospheric conditions play a vital role in determining pollen rain. On a day-to-day basis these conditions are reflected in the weather, and on a long-term basis they constitute the prevailing climate.

The daily weather determines the dynamics of anthesis and dehiscence. Factors such as temperature, windspeed and relative humidity are of primary importance. Daily conditions also control entrainment of pollen in air currents. Involved here is turbulence, related in turn to terrain, vertical wind shear and vertical temperature profile (Mason 1979).

Climate, both in the current season and in previous seasons, is important in determining pollen yield. For example in deciduous trees the quantity of pollen available for spring flowering is established by the end of the previous summer, at which time the cells destined to become pollen grains are already present (Solomon 1979). Therefore, rain and temperature for example, will subsequently influence the amount of pollen produced.

Edaphic factors control both composition of the vegetation and virility of plants, and hence pollen production. Topographic features such as terrain, slope exposure and aspect also fall into this category.

These biotic and abiotic features initially determine the amount of pollen in the atmosphere. Thereafter, the proportion of pollen rain deposited on the earth's surface is a function of aerosol physics which determine settling rates of the pollen. Settling rates are in turn controlled by size, shape and density of the pollen grain (Harrington 1979). The behaviour of the pollen grain is also influenced by different climatic conditions. For example, deposition will vary with different degrees of humidity and precipitation.

Once pollen has settled, factors such as soil moisture, temperature and pH, and resistance of the exine to oxidation and fungal decay, will determine pollen preservation (Traverse 1988). Water-borne pollen may also be transported from one area to another, either by surface wash or in rivers. These many inter-dependent factors determine final composition of the fossil spectrum.

In this study the following questions addressed these interactions in the Pretoria-Witwatersrand-Vereeniging district (PWV) of the Transvaal (Figure 1):

1. What are the qualitative and quantitative relationships between atmospheric pollen and local and regional vegetation?

2. What are the qualitative and quantitative relationships among the atmospheric, surface and subsurface (subfossil) pollen samples, and how do these samples relate to the local and regional vegetation?

3. How can the atmospheric, surface and subsurface samples be used to reconstruct palaeoclimates?

4. What role do meteorological factors play in concentration and distribution of the airspora, and what effect does this have on the interpretation of the airspora?

5 What is the relationship between land-use and pollen rain, given the above interaction?

1.2 Aims

To investigate the above questions, the aims of this project were to

1. sample, identify and quantify the airspora in the PWV

area during 1987 and 1988;

2. identify the meteorological factors that influence the quantities of the airspora in the atmosphere;

3. identify the relationship between the local vegetation and the pollen rain;

4. identify how the land-use patterns influence the pollen rain;

5. quantify the differences between pollen recovered from the atmospheric, surface and subsurface samples, and their relationship to the vegetation;

6. quantify the influence of climatic factors on the pollen rain, and hence determine the usefulness of pollen analysis in palaeoenvironmental reconstruction.

1.3 Experimental design

The PWV area of the Transvaal is the centre of industrial and commercial development of the country, yet covers only 1% of total surface area, 13 200 km^2 (Barnard *et al* 1972) (Figure 1). Atmospheric pollen was monitored here for a two-year period, 1987-1988.

Weather data were acquired for stations closest to each sampler from the Weather Bureau in Pretoria.

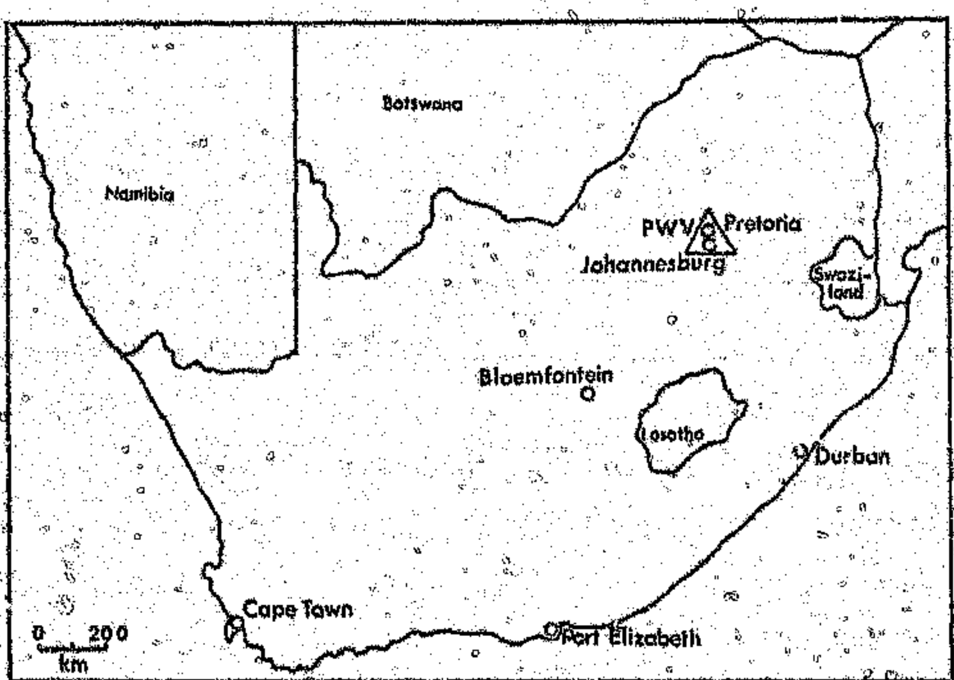

Figure 1 South Africa indicating PWV study area.

At each site a quadrat measuring fifty metres square with the sampler at its centre, was analysed for vegetation.

Surface and subsurface soil samples from each site were analysed for pollen content.

1.4 Climate of study area

Johannesburg and Pretoria are the two major cities in the PWV. Johannesburg is situated at 26° 12'S, 28° 3'E at an elevation of 1753 m above sea level. Daily mean maximum and minimum temperatures are 22°C and 10.5°C, with 811 mm summer rainfall per annum (Climate of South Africa 1986).

Pretoria lies seventy kilometres to the north of Johannesburg at 25° 4'S, 28° 11'E. The elevation is 1300 m. At 25.4°C and 12.2°C mean summer and winter temperatures are slightly warmer than those of Johannesburg. Rainfall is less at 716 mm per annum (Climate of South Africa 1986).

1.5 Vegetation of study area

1.5.1 Native vegetation

The native vegetation of the major portion of the PWV is grassland, classified as Bankenveld (Acocks 1975). The predominantly tall grasses in approximate order of abundance are *Hyparrhenia* species, *Themeda triandra*, *Eragrostis* species, *Sporobolus* species, *Trachypogon spicatus* and *Aristida* species. Of these *Hyparrhenia* species comprise about eighty percent. *Stoebe vulgaris* and *Helichrysum kraussii* are common. Rocky hills and ridges carry woody vegetation, with *Protea caffra*, *Acacia caffra*, *Celtis africana*, *Rhus pyroides*, *Olea europeae* subspecies *africana* and sometimes *Protea welwitschii*. In sheltered valleys *Kiggelaria africana*, *Rhus leptodictya*, *Halleria lucida*, *Leucosidea sericea* and *Buddleja salviifolia* can be found.

The Bankenveld of the southern area of the PWV merges with the Sourish Mixed Bushveld of the Tropical Bush and Savanna Type in the vicinity of Pretoria (Acocks 1975). Vegetation comprises an open savanna with a fairly dense, tall grassveld. Dominant grasses are *Cymbopogon plurinodis*, *Themeda triandra* and *Hyparrhenia* species. Principal trees are *Acacia caffra*, *A. karroo*, *A. robusta*, *A. tortilis*, *Rhus* species, *O. europeaea* subspecies *africana*, *Grewia* species, *Peltophorum africanum*, *Pappea capensis*, *Dichrostachys cinerea*, *Dombeya rotundifolia*, *Combretum zeyheri*, *Sclerocarya birrea*, *Ziziphus mucronata* and *Burkea africana*.

1.5.2 Alien vegetation

Trees predominantly of the northern hemisphere are extensively cultivated throughout the PWV. They are planted in gardens and parks, along streets and more recently on light industrial and commercial estates. The most common genera include *Ulmus*, *Morus*, *Fraxinus*, *Populus*, *Platanus*, *Betula*, *Salix*, *Cedrus*, *Cupressus*, *Quercus* and *Pinus*.

Australian eucalypts are ubiquitous and various species of Australian *Acacia* are common.

All South African plants including those which are naturalised were named according to Gibbs Russell *et al* (1985, 1987). *Cedrus deodara* was after Tutin *et al* (1964). All others were according to Hooker and Jackson (1895).

1.6 Sampling localities

Ten samplers were located at the atmospheric sampling sites of Johannesburg City Health Department, State Health Department, Atmospheric Sciences Division of the Council for Scientific and Industrial Research (CSIR), and one at the University of the Witwatersrand (Figure 2). These sites satisfied the following criteria.

1. They were representative of two of the areas defined by the South African Weather Bureau, based on Koppen's classification, with modifications due to conventional geographic, climatic and agricultural boundaries. These are Northern Transvaal (hot steppe, summer rainfall), and Highveld, including Southern Transvaal, Eastern Orange Free State and Lesotho (warm temperature, summer rainfall).

2. The sites were representative (Table 1) of the following veld types (Acocks 1975):

   a) Bankenveld, of the False Grassveld Type.

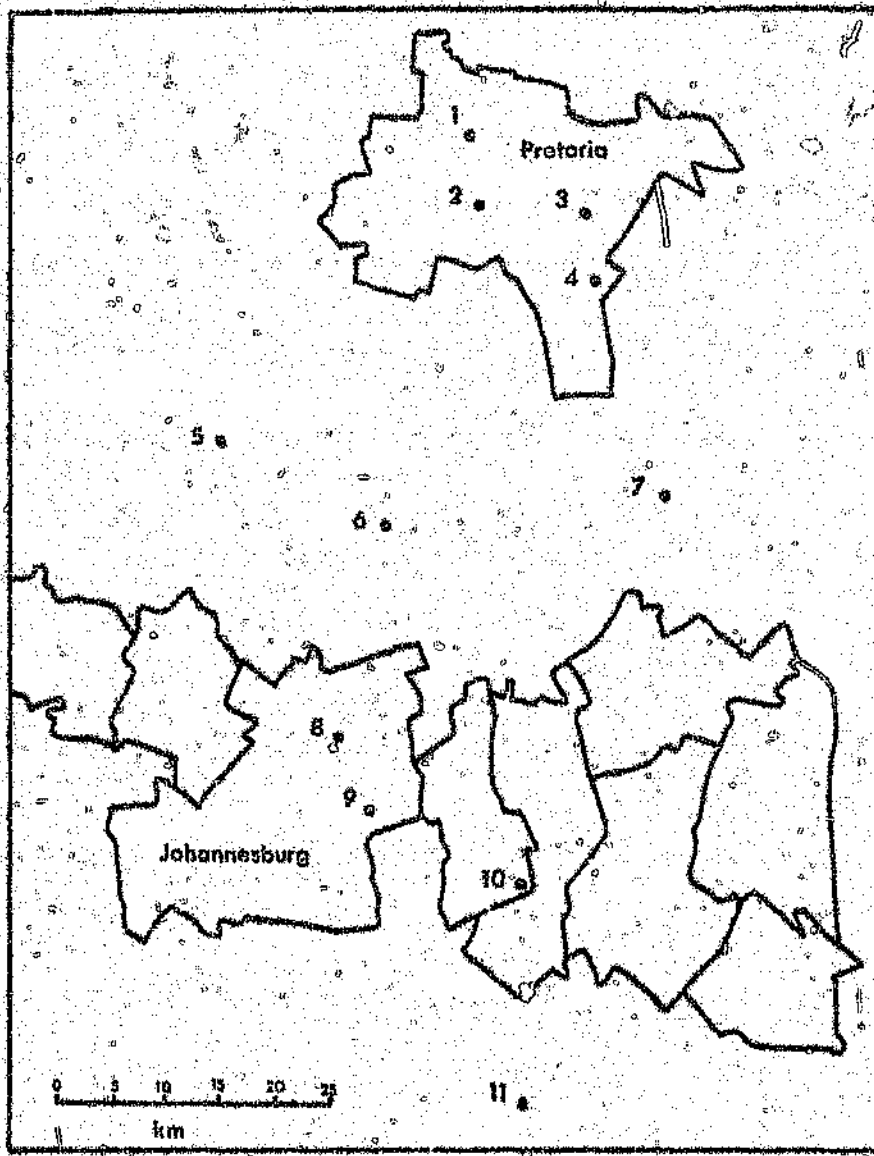

Figure 2 Location of sampling sites
(delineated areas signify municipalities).

b) Sourish Mixed Bushveld, of the Tropical Bush and Savanna type.

3. A cross section of land-use types, ranging from urban through suburban and peri-urban to rural environments, gave a wide spectrum of taxa commonly found in the PWV.

4. The sites were easily accessible for weekly sampling.

Table 1 **Classification of study sites.**

Vegetation Type	Situation	Site	Site No.
Sourish Mixed Bushveld	Suburban/Rural	Wonderboom	1
	Urban	Sunnyside	2
	Suburban/Rural	CSIR	3
Bankenveld	Rural	Garsfontein	4
	Peri-urban	Northern Works	5
	Suburban	Frankenwald	6
	Rural	Welbekend	7
	Urban	Wits	8
	Suburban	South Hills	9
	Peri-urban	Rondebult	10
	Rural	Heidelberg	11

1.7 Site description

1. 'Wonderboom' was a caravan park on the outskirts of suburban northern Pretoria. On its northern border the park was bounded by an east-west trending ridge. Vegetation in the park was similar to that of the surrounding suburbs, ie a

mix of native and alien trees. Ground cover was largely *Pennisetum clandestinum.* Vegetation of the ridge was exclusively native. About five hundred metres from the sampler a small river flowed northwards through the ridge. *Phragmites* species and *Typha capensis* grew along the river banks.

2. 'Sunnyside' was a vacant lot on the perimeter of Pretoria city centre. Trees in the vicinity were predominantly alien. Ground cover was approximately one third *Cynodon dactylon*, one third soil and one third developed (buildings, concrete paths and roads).

3. 'CSIR' was at the eastern suburban outskirts of Pretoria and comprised several hectares of native vegetation surrounding the buildings of the CSIR. Several low lying ridges to the west, east and north were also covered with native vegetation. A suburban area lay to the south. There cultivated taxa included annuals and trees predominantly of the northern hemisphere.

4. 'Garsfontein' was a cemetary in the south-eastern rural district of Pretoria. Ground cover accounted for about eighty percent of the area. This consisted mostly of native grasses, with small areas of *Pennisetum clandestinum*, and concrete structures. The remaining twenty percent was divided about equally among *Acacia karroo*, *A. melanoxylon* and *Populus canescens*. The latter two were naturalised species. There

were several *Combretum apiculatum* planted in the grounds. Adjoining the cemetary was a small-holding with a garden of alien trees. The sampler was located about eight hundred metres from a small river which flowed into a marsh in the east. *Phragmites* species and *Typha capensis* were common.

5. 'Northern Works' was a sewerage reticulation plant in the peri-urban district north-west of Johannesburg. Vegetation occupied about ninety-five percent of the area; and was essentially *Hyparrhenia*. Several *Populus deltoides* grew in a nearby rivercourses as did *Phragmites* species and *Typha capensis*.

6. 'Frankenwald' comprised several hectares of largely undeveloped land on the suburban/peri-urban boundary of northern Johannesburg. Several sports fields on the property were grassed with *Cynodon dactylon*. The remaining area was mostly *Hyparrhenia* grassveld, with some *Pennisetum clandestinum* in the vicinity of a small cluster of buildings. There were several specimens of *Populus deltoides* and many *Populus canescens* along the stream forming the northern boundary of the property. *Phragmites* species and *Typha capensis* occurred.

7. 'Welbekend' was a country police station north-east of Johannesburg. *Hyparrhenia* veld predominated, with small patches of *Cymbopogon/Themeda*. Naturalised *Acacia melanoxylon* occupied about five percent of the area. *Zea mays* was cultivated within about two kilometres. The gardens immediately surrounding the buildings were planted with *Populus deltoides*.

Rhus lancea and annuals. A marshy area lay to the north of the site, about five hundred metres from the sampler. Again *Phragmites* species predominated, with some *Typha capensis*.

8. 'Wits' was sited on the university campus on the urban/suburban border of Johannesburg. This was the only sampler that was elevated, to a height of about eighty metres above ground. Campus vegetation comprised about twenty percent of the area immediately surrounding the sampler, and was mostly alien. So too were the trees on sidewalks and in office gardens, off campus.

9. 'South Hills' was located at the southern limit of Johannesburg's suburbs. It was a water reservoir in the centre of a large tract of undeveloped land. Vegetation was *Hyparrhenia* grassland with a few naturalised *Acacia melanoxylon* trees.

10. 'Rondebult' was a sewerage reticulation plant in the peri-urban district south-west of Johannesburg. Vegetation on the property was all alien with *Pennisetum clandestinum* comprising the major ground cover. Buildings covered approximately fifteen percent of the area. An avenue of trees about five hundred metres long consisted of *Eucalyptus* species and *Cedrus deodar*. Vegetation surrounding the property was *Hyparrhenia* grassland. Surrounding the sewerage plant on all but the eastern boundary was an extensive marshland vegetated with *Phragmites* species and smaller amounts of *Typha capensis*.

11. 'Heidelberg' was south-west of Johannesburg in the Suikerbosrand Nature Reserve. Vegetation was wholly Bankenveld with *Hyparrhenia* species covering the major part of the park. On ridges there were clumps of *Rhus* species, *Heteromorpha trifoliata*, *Diospyros lycioides*, *Euclea crispa*, *Acacia karroo* and *A. caffra*. Farmlands to the north of the reserve had wind shelters comprised of *A. melanoxylon* and *Populus deltoides*. There was a marsh on the northern boundary of the reserve. *Phragmites* species were abundant and some *Typha capensis* occurred.

1.8 Methods and materials

1.8.1 Apparatus

Atmospheric samples

Two sampling methods were used. Simple gravity samplers were located at each site (Figure 2), and two Burkard samplers at two of these sites, one in Pretoria (site 3) and one in Johannesburg (site 6).

Gravity samplers are adequate if surface deposition of pollen is to be measured over short periods (Raynor 1979). It is also a simple, quick and economical method of assessing the pollen content of the air. The apparatus used consisted of a two-tiered platform, the upper tier serving as a rain cover. The lower tier held four microscope slides, each facing one of the cardinal compass directions, and placed at an angle of forty-five degrees to the horizontal. A fifth slide was placed flat on the upper tier. The slides were coated with vaseline.

Slides were collected weekly. The vaseline was dissolved with xylene and the residue from all five slides was combined. Acetolysis followed Faegri and Iverson (1975). Pollen was stained with Safranine and water mounts were read at a magnification of 400, until 250 pollen grains had been counted. During winter months such counts were not possible. Weekly data were progressively summed for the two-year study period.

As gravity slides are inadequate for particles smaller than 15 um, this method was not applied to fungal spore analysis.

Where atmospheric content is being investigated rather than surface deposition, a suction sampler is the recommended method (Raynor 1979). The Burkard Seven Day Recording Volumetric Spore Trap has been extensively used abroad (Levetin & Buck 1980, Strandhede *et al* 1984, Anderson 1985, Spieksma *et al* 1985) and permits standardised comparisons to be made internationally. This apparatus samples air as a function of time, consistently into the wind. Particles are aspirated through a narrow orifice at 10 ℓ $minute^{-1}$, so that a total of 14,4 m^3 of air passes through the trap in twenty-four hours. Particles entering the orifice are impacted onto transparent tape thinly coated with vaseline. The tape is attached to a revolving drum which completes a revolution in seven days, turning at 2 mm $hour^{-1}$.

At the end of each week the strip was cut into seven equal sections. Daily strips were mounted in 50% glycerine stained with Safranine. Three randomly selected longitudinal bands corresponding to the length of the strip, each 0,33 mm wide were scanned on each daily strip. This provided a direct count of the airspora contained in one m^3 of air (of the total of 14.4 m^3) in a twenty four hour period (Spieksma 1983). This method of scanning was used notwithstanding the effects of transverse inequalities (Käpylä & Penttinen 1981), as insects often lodged between the intake orifice and the tape. The resultant obstruction made transverse scans impracticable. Moreover tremendous circadian variation was noted in preliminary analysis so that longitudinal scanning was preferable. Anderson (1985) and Atluri *et al* (19?8) made similar reports.

Strips were read at a magnification of 400. An oil immersion lens of 1000x was used for clarity in difficult cases. Identification was aided by reference to both a slide collection and to the literature (Hyde & Adams 1958, Gregory 1973, Moore & Webb 1978). Air intake was checked weekly.

All instruments were erected to sample air at 2 m above ground, with the exception of the sampler at site 8 where a ground level situation was impracticable. This siting of samplers was chosen because this study required an assessment of pollen in the immediate vicinity, as opposed to a regional survey. The number of samplers and their wide distribution facilitated such a detailed analysis. In addition, if the allergenic potential of the atmosphere were to be examined it was reasoned that the air to which the public was generally exposed would be the pertinent component. Gregory and Hirst (1957) found the concentration of airspora to be considerably greater at 24 m above ground than at ground level.

Soil samples

A 3.5 cm soil auger was used to collect soil samples from nine of the eleven sites. The urban sites (2 and 8) were excluded as there was no suitable undisturbed soil in the vicinity of the samplers. With the exception of sites 4, 7, 10 and 11, cores were taken beside the gravity samplers. The four former sites were sampled in the nearby marshy areas mentioned above.

Six-centimetre cores were drilled and divided into two. The upper and lower three-centimetre portions were considered as surface and subsurface samples, respectively. No depositional time period was specified or intimated by this sampling. The rationale was simply that a buried sample would contain that element of pollen that would ultimately become fossilised. Thus the subsurface sample was considered a subfossil sample.

Three random samples from each locality were cored and placed in plastic bags. In the laboratory these three samples were combined for analysis. After thorough mixing, 100 g extracts from each of the combined samples were macerated following standard laboratory procedures (Gray 1965).

1. 10% Hydrochloric acid (HCl) added to dissolve carbonates.
2. Residue washed in distilled water to remove HCl.
3. 40% Hydrofluoric acid (HF) added to remove silicates.
4. Residue washed in distilled water to remove HF.
5. Zinc chloride ($ZnCl_2$) mineral separation applied to residue to

separate pollen.

6. Polleniferous float washed in distilled water to remove $ZnCl_2$.
7. Polleniferous residue acetolysed to remove celluloses (Faegri & Iverson 1975).
8. Pollen stained with Safranine and mounted on microscope slides using Depex mounting medium.

Slides were scanned at a magnification of 400, or greater when clarity demanded, until a pollen count of 250 grains was recorded (wherever possible).

1.8.2 Vegetation sampling

At each site apart from the urban sites 2 and 8, a quadrat measuring fifty metres square was demarcated around the gravity samplers. Vegetation was measured within each quadrat, each taxon expressed as a percentage of total vegetation in the given area. Percentage referred to canopy cover for trees and shrubs and to area cover for herbaceous taxa and grass. Area of the first three was calculated by measuring radii. Area of grass was calculated by subtracting the combined areas of these three from the total vegetated area of each quadrat. Thus all vegetation was expressed in terms of area cover.

1.8.3. Weather data

Data from weather stations at Pretoria Forum (located in central city) and Jan Smuts Airport (north-east of Johannesburg) were considered representative of Sourish Mixed Bushveld and Bankenveld. These were the only first order weather stations in the PWV, supplying data for all parameters selected. Second and third order weather stations located closest to sampling sites supplied rainfall and temperature data (South African Weather Bureau 1987, 1988). Data for remote sites were obtained from the atmospheric sampling sites on location, mentioned above.

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Chapter 2

Incidence of Atmospheric Pollen

2.1 Introduction

In South Africa there have been no aerobiological reports since those of Ordman (1947, 1963). This science has made significant advances, particularly in the northern hemisphere. There the allergenic potential of the airspora 's constantly under review. It is likely that the airspora in South Africa has changed since Ordman's studies were undertaken. Industrialisation has altered land-use patterns, and horticultural practices are different. Sampling equipment has improved so that smaller particles can now be detected. This chapter presents pollen calendars for Pretoria and Johannesburg. Allergenicity is discussed.

2.2 Methods

Methods and materials for data collection are described in section 1.8.

2.2.1 Pollen calendars

Pollen calendars were constructed for Pretoria and Johannesburg using data from the Burkard samplers at sites 3 and 6 (Figures 3

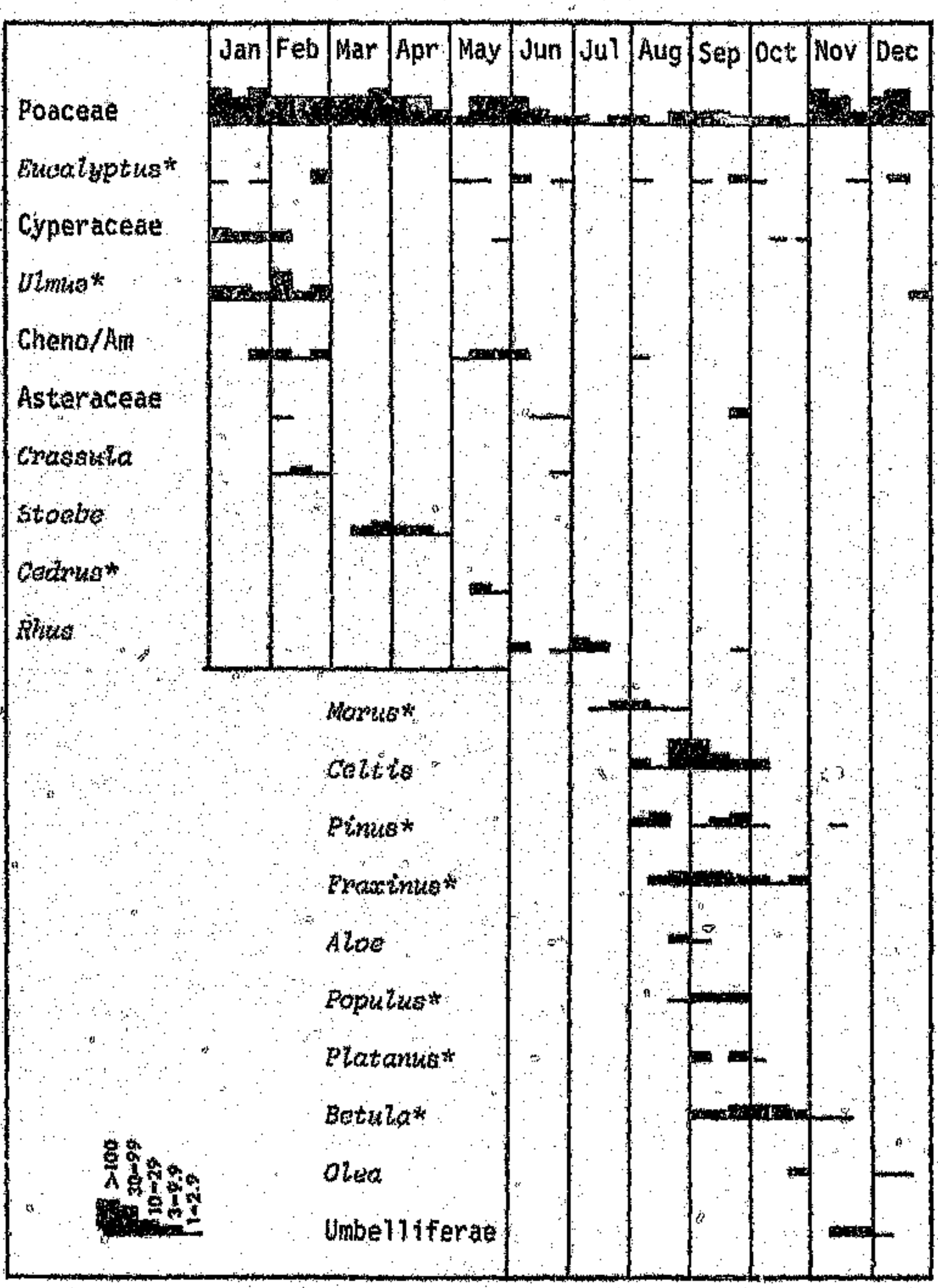


Figure 3 **Pollen calendar for Pretoria**

(* = taxa comprised exclusively of alien species;
Cheno/Am = Chenopodiaceae/Amaranthaceae;
measurement in grains m^3 of air daily).

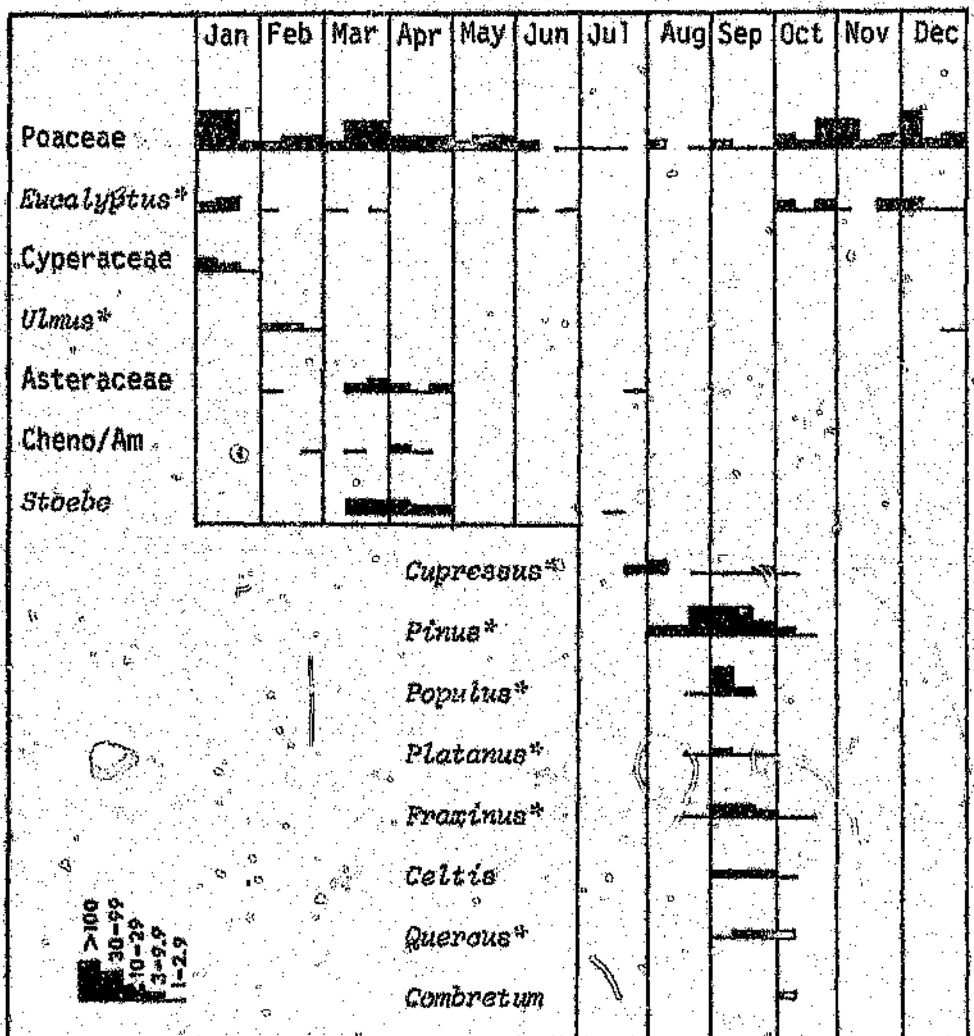


Figure 4 Pollen calendar for Johannesburg

(* = taxa comprised exclusively of alien species; Cheno/Am = Chenopodiaceae/Amaranthaceae; measurement in grains m^3 of air daily).

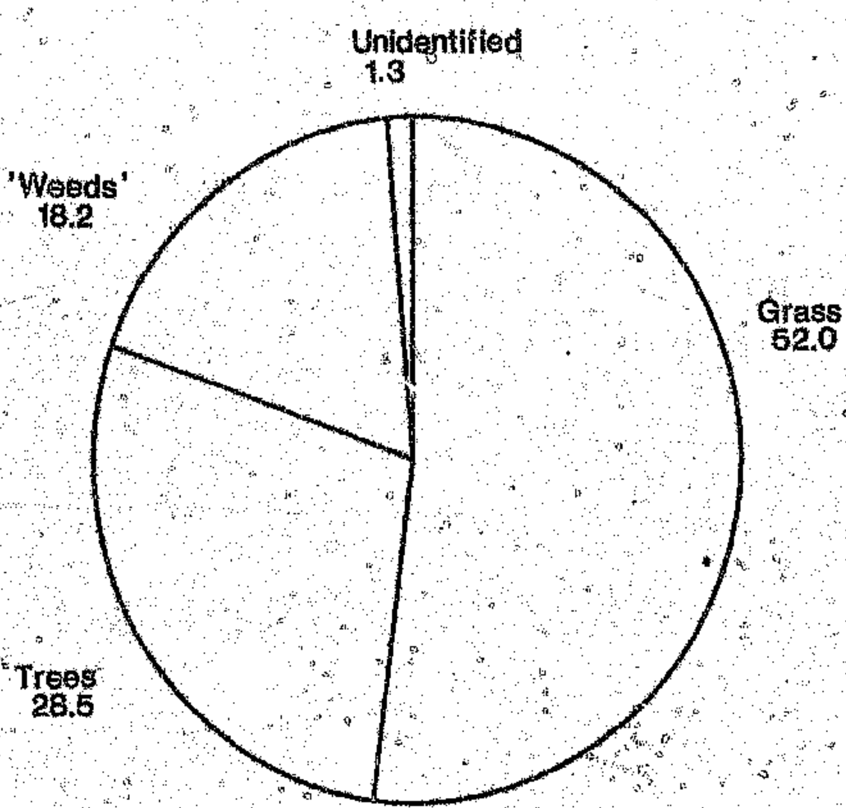


Figure 5   Percentage of pollen, by category.

& 4). Monthly pollen counts were first averaged for 1987 and 1988. Then three ten-day (decade) means were calculated for each month, with pollen expressed as the daily average m^{-3} of air. All taxa which daily exceeded three grains m^{-3} were included in the calendars.

The onset and close of the pollen season for each taxon were first and last days registering at least one pollen grain m^{-3} of air. This method was used rather than a percentage related start/end of pollen season (Nilsson & Persson 1981), as in most cases the season was so short that a calendar was meaningless.

2.2.2 Pollen production

Annual totals of daily pollen counts m^{-3} of air and percentages $taxon^{-1}$ were calculated (Tables 2 & 3). Highest daily count is displayed. Only taxa constituting more than one percent of the total are shown individually.

Data were analysed seasonally by averaging counts for 1987 and 1988 (Table 4).

Figure 6 differentiates between grasses, trees and 'weeds' which include veldflowers and garden plants. These are categories used by allergists. Table 5 separates grasses from native and alien taxa.

Table 2 Annual totals of daily pollen counts for Pretoria

(No. = grains m^{-3}
% = percentages of annual counts $taxon^{-1}$
Max. = highest daily count $taxon^{-1}$
Cheno/Am. = Chenopodiaceae/Amaranthaceae).

1987				1988			
Taxon	No.	%	Max.	Taxon	No.	%	Max.
Poaceae	10090	64.8	179	Poaceae	5119	49.8	175
Celtis	827	5.3	121	*Celtis*	1450	14.1	93
Betula	532	3.4	39	*Fraxinus*	657	6.4	27
Eucalyptus	515	3.3	16	*Pinus*	385	3.7	54
Ulmus	513	3.3	66	*Ulmus*	362	3.5	62
Fraxinus	346	2.2	35	*Betula*	272	2.6	19
Pinus	334	2.1	54	Cheno/Am.	242	2.4	12
Cheno/Am.	311	2.0	12	*Eucalyptus*	227	2.2	8
Olea	303	1.9	89	*Rhus*	227	2.2	12
Cupressus	250	1.6	56	Cyperaceae	196	1.9	16
Cyperaceae	203	1.3	19	*Populus*	196	[illegible]	12
Populus	171	1.1	47	*Platanus*	12[illegible]	1.2	23
Total	14395	92.5		Total	94[illegible]	91.9	
Others	1173	7.5		Others	830	8.1	
Sum Total	15568	100.0		Sum Total	10284	100.0	

Table 3 Annual totals of daily pollen counts for Johannesburg

(No. = grains m^{-3}
% = percentages of annual counts $taxon^{-1}$
Max. = highest daily count $taxon^{-1}$
Cheno/Am. = Chenopodiaceae/Amaranthaceae).

1987				1988			
Taxon	No.	%	Max.	Taxon	No.	%	Max.
Poaceae	6169	42.6	190	Poaceae	6740	50.8	210
Pinus	1466	10.1	214	*Pinus*	1273	9.4	97
Populus	763	5.3	233	*Fraxinus*	608	4.5	51
Eucalyptus	749	5.2	70	*Populus*	577	4.2	74
Fraxinus	710	4.9	82	*Eucalyptus*	560	4.1	27
Stoebe	538	3.7	93	*Stoebe*	478	3.5	47
Asteraceae	427	3.0	47	*Ulmus*	444	3.3	19
Celtis	409	2.8	47	Asteraceae	402	3.0	27
Cupressus	385	2.7	98	*Cupressus*	318	2.3	51
Cyperaceae	263	1.8	31	*Celtis*	315	2.3	31
Betula	220	1.5	70	*Betula*	278	2.0	16
Platanus	210	1.5	19	Cyperaceae	233	1.7	16
Quercus	194	1.4	50	*Platanus*	153	1.1	16
Solanaceae	194	1.4	39	*Quercus*	147	1.1	27
Cheno/Am.	190	1.3	12	Cheno/Am.	139	1.0	8
Ulmus	186	1.3	35				
Total	13073	90.3		**Total**	12665	93.0	
Others	1402	9.7		Others	952	7.0	
Total Sum	14475	100.0		**Total Sum**	13617	100.0	

Table 4 Annual percentage of pollen expressed seasonally.

	Johannesburg		Pretoria		PWV
	1987	1988	1987	1988	1987/88
All year	49.3	55.4	71.9	58.7	58.8
Spring	32.4	27.6	21.2	32.3	28.4
Summer	7.9	8.0	4.0	4.8	6.2
Autumn	9.1	3.0	1.4	1.0	4.9
Winter	1.3	1.0	1.5	3.2	1.8

Table 5 Annual percentage of pollen grouped to indicate origin.

(N.H. = northern hemisphere
S.H. = southern hemisphere).

	Johannesburg		Pretoria		PWV
	1987	1988	1987	1988	1987/88
Poaceae	42.6	50.8	64.8	49.8	52.0
Native	20.5	15.6	15.8	24.4	19.1
Alien (N.H.)	29.8	27.9	14.8	21.9	23.6
Alien (S.H.)	5.6	4.7	3.4	2.4	4.0
Unidentified	1.5	1.0	1.2	1.5	1.3

2.3 Results

2.3.1 Pollen calendars

Grass

The anemophilous grasses were most significant. Table 4 shows that 58.8% of pollen in the PWV showed no seasonality. This was largely due to the input of grass pollen. The peak grass season was between October and March. The onset of the main season did not vary appreciably between 1987 and 1988, for grass and all other taxa as well.

Trees

The an[illegible]ilous northern hemisphere trees made a significant contribution. The regional average was 23.6% of total pollen for the two-year period (Table 5). These trees were all seasonal, with the majority flowering over a very abbreviated spring season.

The flowering period of most seasonal tree taxa started earlier in Pretoria. For example *Celtis* started in the first decade of August in Pretoria, and a month later in Johannesburg. *Fraxinus* started in the second decade of August in Pretoria, and in the last decade of August in Johannesburg. *Ulmus* started in the second decade of December in Pretoria, and in the last decade in Johannesburg.

Ulmus was represented principally by *U. parvifolia*, *Morus* by both

M. nigra and the naturalised species *M. alba*, *Populus* by the naturalised species *P. canescens*, *Platanus* by *P. acerifolia*, *Betula* by *B. pendula* and *Cedrus* by *C. deodara*. Several species contributed to each of *Cupressus*, *Quercus*, *Ligustrum* and *Pinus*.

Australian *Eucalyptus* were ubiquitous with species pollinating in successive months. Relatively large numbers of this entomophilous pollen were found, frequently clumped. Entomophilous Australian *Acacia* species were also recorded in fair numbers.

Native tree taxa were poorly represented in the atmospheric sample. Only *Celtis*, *Rhus*, *Olea* and *Combretum* species occurred in appreciable numbers.

Differences were seen between Johannesburg and Pretoria in the quantities of pollen of specific native tree taxa. In Pretoria there were greater quantities of *Celtis*, *Rhus* and *Olea* species.

Trees not specifically mentioned here but seen in the pollen calendar were not significantly represented in the atmospheric sample.

'Weeds'

Herbaceous and small woody taxa termed 'weeds' by allergists, were common (Figure 8). The majority were veldflowers, mostly Asteraceae eg *Senecio vulgaris*, *Artemisia* and *Helichrysum* species. The latter and several other Asteraceae are collectively grouped in the pollen calendars (Figures 3 & 4) as their pollen was difficult to differentiate.

Other native plants in this category were species of *Crassula*, *Euphorbia*, *Aloe*, *Convolvulus*, *Anthospermum*, Liliaceae eg *Asparagus*, Solanaceae, Umbelliferae and *Myrothamnus flabbelifolia*. A limited number of Cyperaceae were recorded throughout the year.

The small percentage of alien weeds was principally confined to the Asteraceae. Included were both garden flowers and traditional weeds eg *Taraxacum* species, *Bidens pilosa*, *Tagetes minuta* and *Cosmos bipinnata*.

Other common weeds were *Tribulus* and *Plantago* species and taxa of the Chenopodiaceae/Amaranthaceae. This group included native and alien plants, ranging from weeds to garden plants. They flowered throughout the year.

With the exception of *Stoebe vulgaris* and the Chenopodiaceae/ Amaranthaceae, herbaceous taxa occurred only incidentally and in small numbers. As a group however they constituted 18.2% of annual pollen output (Figure 5). They were predominantly entomophilous and seasonal, but many had a very long flowering season. Moreover in the Asteraceae the flowering seasons of different species overlapped, so that the effective season was almost continuous.

2.3.2 Pollen production

Grass was again the major contributor with a regional average of 52% (Table 5). The highest daily grass count, 210 grains m^{-3} occurred in Johannesburg (Table 3). The highest count in any other taxon was recorded for *Populus*, with 233 grains m^{-3} measured in Johannesburg (Table 3). However, the regional average for 1987/88 for *Populus* was only 3.13%.

2.3.3 Annual variability

There were marked inter-annual differences in pollen production (Tables 2 & 3). Variation was both absolute and relative. The greatest absolute anomaly was the fifteen percent difference in grass pollen between 1987 and 1988 at Pretoria. Relative between-year variability can be seen in ordination of taxa. Only first and second rankings were consistent, ie Poaceae, *Celtis* and *Pinus*.

2.4 Discussion

From the foregoing results there is good reason to believe that there is an allergenic problem in the PWV. Pollen, especially of grass, is widely recognised as one of the major causes of upper respiratory tract allergy (Ordman 1947, Ausdenmoore 1981, Brinkfelt *et al* 1982, O'Rourke & Lebowitz 1984). In this study grass comprised the major component of the atmospheric pollen spectrum (Figures 3 & 4). Considerable tree pollen was also recorded, and this, too, has been implicated as a source of allergy.

2.4.1 Grass

Grass comprised 52% of the regional total of atmospheric pollen during the study period (Table 5). Although individual species were seasonal, species flowered consecutively so that at no time in the year was grass pollen absent from the atmosphere. As all grass pollen is morphologically similar at the species level, it was difficult to isolate species in the atmospheric samples. However, field observation showed that *Hyparrhenia* was most abundant, with smaller numbers of other native grasses. *Hyparrhenia* accounted for about 80% of grasses found in the PWV, and the anthers were well exposed to wind, about 1.5 m above ground. *Cynodon dactylon* and the exotic *Pennisetum clandestinum* were common on lawns and sports fields, but atmospheric pollen was probably minimal and very localised. *Cortaderia selloana* was planted to stablise goldmine dumps, so that pollen was also only locally significant.

2.4.2 Trees

Northern hemisphere tree pollen was well represented in terms of absolute numbers and relative percentages (Tables 2 & 3). Their season was shorter here than in the northern hemisphere (Leuschner & Boehm 1981, Spieksma 1983), presumably because of the rapidly increasing temperatures in our spring. Seasons were not as well defined as in the northern hemisphere. In the PWV spring and autumn were extremely short. The duration of each was about six weeks in September/October and April/May. Winter spanned June-August, and summer lasted from mid-October to mid-April. For seasonal taxa the flowering season started earlier in Pretoria than Johannesburg. This was probably because of higher temperatures in Pretoria.

Native trees were poorly represented in the pollen spectrum. This was partly due to lack of trees in the natural vegetation and partly due to the entomophily of those which did occur. Only anemophilous taxa were present in appreciable numbers, eg *Rhus* and *Celtis*.

Although Johannesburg and Pretoria are close to each other, the native tree pollen spectrum reflected differences in natural vegetation. The larger numbers of *Rhus*, *Olea* and *Celtis* in Pretoria were indicative of the savanna.

2.4.3 Inter-annual differences

Marked inter-annual differences in pollen production (Tables 2 & 3) has also been documented by Spieksma (1986), working in the Netherlands. Spieksma (1983) suggested that relative percentages were frequently more meaningful than absolute pollen counts. This is true for several reasons. Most pollen falls to the ground within one hundred metres of the source plant (Raynor *et al* 1970). Thus the Burkard sampler aspirates pollen in its immediate vicinity. Although there have been reports of long distance dispersal (Strandhede & Wihl 1981, Mandrioli *et al* 1982, Scott & van Zinderen Bakker 1985, Neiffren 1988), they indicated that atmospheric conditions and terrain were limiting factors.

The major cause of inter-annual pollen differences in this study was probably climatic variation, expressed principally in unreliability of rainfall in South Africa (Tyson 1986). The influence of rainfall will be further examined in Chapter 4.

2.4.4 Allergenic implications

Although pollen is ubiquitously recognised as allergenic, the dose-response concentration threshold for pollen is uncertain. Available information refers to northern hemisphere conditions and taxa. Presumably it is an individualistic parameter, and prevailing atmospheric conditions may either exacerbate or alleviate symptoms.

Davies and Smith (1973) considered 50 grains m^{-3} to be the level above which severe discomfort will be experienced by individuals sensitised to grass pollen. This cut-off point is frequently quoted (Reiss & Koštic 1976, Anderson 1985, Koivikko *et al* 1986). In 1976 Fuckerieder reported that 25 grains m^{-3} elicited a response in 50% of grass sensitive patients, and that 50 grains m^{-3} did so in 100% of such patients. Viander and Koivikko (1978) found that birch sensitive patients reacted to 200 grains m^{-3}. Therefore a general rule of thumb does not apply, with plants differing in amount of pollen which provokes a response.

The allergenic status of South African grasses is undocumented. However, most grasses share allergenicity, so that sensitivity to one taxon will probably indicate sensitivity to other grasses (Chapman & Williams 1984, Bruce *et al* 1985). The likelihood is that our grass species are all suspect. An added problem in the PWV area relates to the long flowering season of grasses. This means that it is incorrect to consider grass allergy a strictly seasonal phenomenon.

The uncertainty regarding allergenicity extends to our other native plants. Northern hemisphere reports again show shared allergenicity in related taxa(Løwenstein 1980, Weber 1981). This means that most species contributing to the pollen calendars of the PWV are potentially allergenic. For example *Celtis laevigata* and *C. occidentalis* are allergenic (Levetin & Buck 1980). In the Ulmaceae,Levetin and Buck (1980) further listed various species of *Ulmus* ranging from minor to major allergens.

The Oleaceae are a serious source of allergy, particularly in Mediterranean regions (Nardi *et al* 1986) where *Olea* is the major contributor. In the PWV *Ligustrum* and *Fraxinus* species were additionally common. *Populus* pollen, abundant in PWV samples, was reported as highly allergenic by Buck and Levetin (1985). *Betula* is responsible for most tree allergy in the northern hemisphere (Spieksma 1983, Strandhede *et al* 1984, Anderson 1985, Koivikko *et al* 1986). In the PWV it was not common but may have been a hazard in localised situations. *Platanus*, *Morus* and *Quercus*, present in fair numbers in the PWV are moderately allergenic (Levetin & Buck 1980). Frengue[illegible] and Mandrioli (1987) found Myrtaceae to cause sporadic pollinosis. Ordman (1963) stated that the entomophily of this taxon, *Acacia* and *Jacar[illegible] mimosifolia* precluded them from being a hazard.

Uncertainty also surrounds entomophilous pollen and its role in allergy. Two limitations are invoked. First, it is considered too large to pass into the smaller airways. Solomon (1986) addressed this point. He reviewed anomolous studies where pollinosis associated with identifiable pollen types did not match incidence of atmospheric pollen. Symptoms occurred either before atmospheric pollen was recorded, or the allergy persisted beyond the pollen season. Similar observations were recorded by Spieksma *et al* (1985). In explanation Solomon (1986) reported evidence of the association of pollen allergens with small particles in the aerosol range. Such allergen particles may elute from pollen grains before their dispersal. If they contain antigens, the size of the intact grains then becomes irrelevant.

Second, entomophilous pollen is thought not to occur in the atmosphere in appreciable numbers. The findings of this project do not support this contention, as fair numbers were recorded, albeit in localised situations.

Allergenicity of the remaining angiospermous trees is obscure. Sap of *Rhus* causes contact dermatitis (LE Davidson personal observation), so that antigens may be present in the pollen as well. Ordman (1963) mentioned that *Schinus molle* was often incriminated but never found conclusively to cause hay fever. Few pollen grains of this and the remaining trees were found.

Pollen of the conifers was produced in large quantities. However, the pollen affects a limited number of people only. Three taxa were abundantly represented in the atmospheric samples of the PWV: *Pinus*, *Cedrus* and *Cupressus*. *Pinus* is reportedly hypoallergenic (Harris & German 1985). Although Ordman reported only one case of pine pollinosis in 1947, he considered *Cupressus* to be the major cause of allergy in patients presenting in the winter-spring period.

Considering the 'weeds', Ordman (1947, 1963) found limited pollinosis associated with the Asteraceae. He reported some incidences of multiple sensitivity to this family, but other cases of specific sensitivity only. *Artemisia* is the composite weed causing most trouble in Europe (Petersen & Sandberg 1981, Strandhede & Wihl 1981, Nardi *et al* 1986, Spieksma 1986). As only small numbers were found in the PWV it was only locally significant. Levetin and Buck (1980) classified *Taraxacum* as a minor allergen. *Stoebe vulgaris* was quite abundant in rural areas of the PWV, but its allergenicity is unknown.

The Chenopodiaceae/Amaranthaceae have been implicated by numerous workers (Romano *et al* 1983, Chapman & Williams 1984), as has *Plantago* (Buck & Levetin 1985, Spieksma 1986). Both Ordman (1947) and Levetin and Buck (1980) reported suspected sensitivity to *Cyperus* species. Umbelliferae was listed as allergenic by Anderson (1985).

The remaining 'weeds' are probably not a cause of concern in the PWV as they occurred infrequently and in small numbers.

2.5 Summary and conclusions

1. Grass pollen was the major component of atmospheric pollen during the study period, comprising 52% of the regional total.

2. At no time in the year was grass pollen absent from the atmosphere, as species flowered sequentially.

3. Northern hemisphere tree pollen was well represented. The flowering season of these taxa was shorter here than in the northern hemisphere.

4. Native trees were poorly represented in the pollen spectrum This was partly due to lack of trees in the natural vegetation and partly due to their entomophily.

5. Although Johannesburg and Pretoria are close to each other, the native tree pollen spectrum reflected differences in natural vegetation.

6. Marked inter-annual differences in pollen production were observed at both sites.

7. The high percentage of northern hemisphere taxa combined with the large numbers of grasses, indicated a poor scenario for allergy sufferers in the region. In addition, the seasonal distribution of atmospheric pollen was unfavourable, with nearly 60% of the annual total being representative of taxa that were non-seasonal.

Chapter 3

Atmospheric Fungal Spore Content

3.1 Introduction

In South Africa the role of fungal spores in upper respiratory tract allergy is recognised, but study has been limited. Ordman's work (1947, 1963) focussed on pollen. His methods were unable to detect spores in quantity, and in addition fungi were considered a coastal hazard, not associated with the dry atmospheric conditions experienced in the PWV, especially in winter.

This chapter details the fungal spore content of atmospheric samples in the PWV.

3.2 Methods

Spore counts from the two Burkard samplers, situated in Pretoria and Johannesburg, were used. Daily data were combined and averaged to produce regional monthly spore counts, which were compared to similar data for pollen (Table 6). Fungal spores were also expressed as a percentage of the total airspora (Figure 6).

Relative spore percentage composition for the PWV was calculated (Figure 7). Dete'led identification of fungal spores was not undertaken. Only taxa that were readily identifiable were individually included. Several other taxa were counted in smaller numbers, and grouped collectively as 'others'. Basidiospores were undifferentiated and also included in this category, as were unidentified fungal spores. The spores of some taxa were not identified from atmospheric samples, but their presence was deducted after successful inoculation of culture plates, using material from the Burkard strips (unpublished).

Monthly data were divided into ten day-periods to produce decade averages, showing annual spore distribution for both sites (Figure 8).

Table 6 Average monthly pollen and [illegible] NW 1987/1988

(number m^{-3} of air day $^{-1}$).

Month	Pollen	Spores
Jan	120	11823
Feb	62	9664
Mar	65	12926
Apr	41	9096
May	30	4673
June	18	3188
July	14	3710
Aug	67	1561
Sept	81	2060
Oct	36	1624
Nov	72	1078
Dec	70	1852

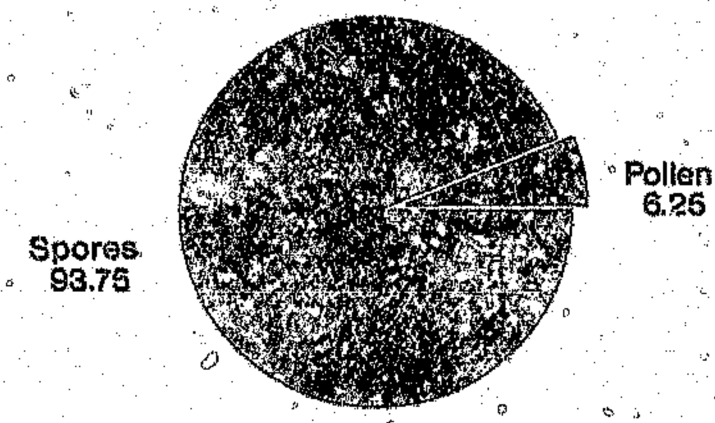


Figure 6. Percentage composition of the airspora.

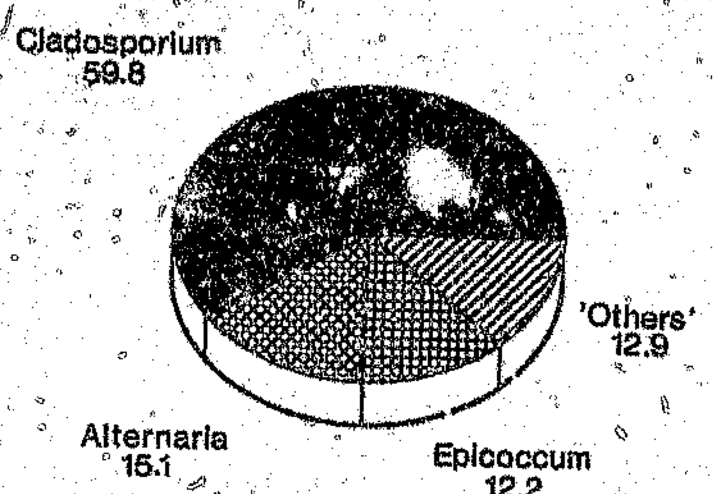


Figure 7 Percentage composition of spore assemblage.

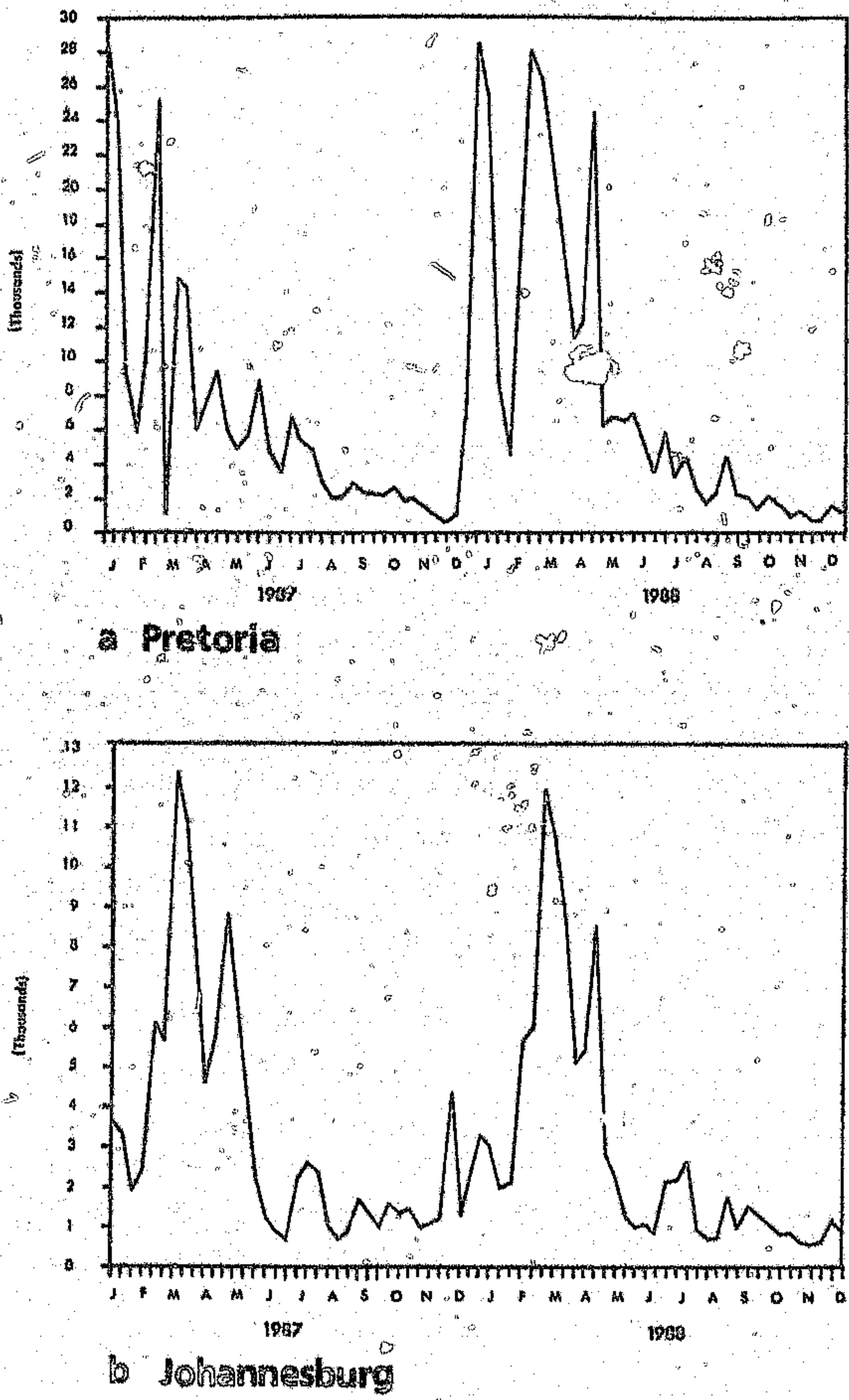


Figure 8 Annual fungal spore distribution.

3.3 Results

Fungal spores constituted 93.75% of the annual total airspora (Figure 6). They were present throughout the year, although the major spore season occurred in summer (Figure 8). Regionally, average counts varied from about 1 000 spores m^{-3} in the low season to about 13000 spores m^{-3} in the high season.

In Johannesburg maximum spore production occurred between January and March, and in Pretoria between December and April.

Cladosporium species contributed 59.8% to the annual regional spore total (Figure 7). Other genera that occurred in large numbers were *Alternaria* and *Epicoccum*. Taxa that were the most common in the category 'others' were *Curvularia*, *Drechslera*, *Fusarium*, *Pithomyces*, *Torula*, *Nigrospora* and *Stemphylium*. *Penicillium* and *Aspergillus* were only detected from the culture plates (unpublished).

3.4 Discussion

The above results suggest that there is an allergenic problem in the PWV, apart from that caused by pollen. Fungal spores are widely recognised as an agent in upper respiratory tract allergy (Anderson 1985, Aukrust *et al* 1985). In the PWV they were recorded in large quantities, often in excess of the threshold level for sensitivity of 3 000 spores m^{-3} (Bagni *et al* 1977).

Fungal spores were several orders of magnitude greater than pollen counts throughout the year (Table 6), comprising the major proportion of the total of all airspora (Figure 6). Other studies produced similar data. For example Vittal and Krishnamoorthi (1988) found that fungi contributed 87.2% to the airspora in Madras, India. Even during the dry months and notwithstanding frost conditions, fungi were copious in the PWV.

The predominance of the fungi imperfecti are supported by studies elsewhere (Larsen 1981, Vittal & Krishnamoorthi 1988). This group comprises the fungi most important in terms of allergy (Aukrust & Borch 1985). Not only the spores but also the mycelia are allergenic (Aukrust *et al* 1985).

Of the fungi imperfecti *Cladosporium* species were dominant (Figure 7). This seems to be a world-wide phenomenon, with many reports of similar results (Davies *et al* 1963, Levetin & Horowitz 1978, Rubulis 1983).

The earlier and longer peak season in Pretoria (Figure 8) was probably caused by higher temperatures, and hence earlier development of host plants there. This follows the same pattern as the pollen calendars (Figures 3 & 4).

The difficulties of identification of fungal spores from atmospheric samples are commonly acknowledged (Rubulis 1983, Anderson 1985). Aukrust and Borch (1985) among others, have pointed out the limitations of the taxonomy and the uncertainty of allergenicity of the many strains in each species. In addition many fungi have several spore producing stages indistinguishable from one another. It is uncertain whether all stages or only limited periods are allergenic.

3.5 Summary and conclusions

1 At 93.75%, fungal spores constituted the major part of the annual total airspora in the PWV.

2. Fungal spores were several orders of magnitude greater than pollen counts throughout the year, cold and dry winter conditions notwithstanding.

3. The fungi imperfecti comprised in excess of 87% of the total spore assemblage. Of this, *Cladosporium* contributed the major proportion.

4. As with pollen, the peak season occurred earlier and lasted longer in Pretoria than in Johannesburg.

Chapter 4

The Role of Meteorological Factors in Concentration and Distribution of the Airspora

4.1 Introduction

Concentration and distribution of the airspora are related to meteorological factors. Current weather conditions (Frinking 1977, Ljungkvist *et al* 1977, McDonald 1980) and those of previous seasons (Anderson 1980, Koivikko *et al* 1986) are involved. However, a relationship between meteorology and airspora does not necessarily indicate causality, as several other factors may play a role (Bringfeld *et al* 1982, Mäkinen 1977, 1985). These factors function spatially, eg vegetation zones, topography and soil conditions. Physiology and phenology of the plant also contribute to variation in airspora.

Meteorological data are significant in forecasting high allergy days. If advance knowledge is available, clinicians and allergy sufferers can take appropriate precautions.

This chapter examines the role of meteorology in concentration and distribution of airspora in the PWV.

4.2 Methods

Data from the Burkard samplers for sites 3 (Pretoria) and 6 (Johannesburg) were analysed (Chapter 1.8). The decade averages for grass pollen (Chapter 2.2.1) and fungal spores (Chapter 3.2) were used. Only the grass component of the total pollen suite was considered as the amount of pollen produced by other taxa was relatively small, and the pollen seasons were very abbreviated as explained in Chapter 2. The main season apart from the extended grass season was spring for which there were too few data points to validate statistical analysis. Also, at 58.8% much of the total pollen was non-seasonal (Table 4) eg Compositae, *Eucalyptus* and Cyperaceae, so that correlation with seasonal meteorological factors was meaningless.

Meteorological data (Table 7) were selected after reference to similar studies (Reiss & Kostic 1976; Bringfelt *et al* 1982, Lyon *et al* 1984). The data were obtained from the South African Weather Bureau's first order meteorological stations closest to the samplers. In Pretoria this was a city station about seven kilometres from site 3. The Johannesburg station was at Jan Smuts airport about ten kilometres from site 6.

Apart from rainfall, daily measurements were calculated to give ten-day averages corresponding to pollen and spore data. For rainfall ten-day periods were summed.

Radiation was measured in the [illegible] the weather station only. This was at Irene, midway between sites 3 and 6.

Weather conditions which varied during the day were recorded three times daily at 8h00, 14h00 and 20h00. These were relative humidity, pressure and windspeed.

Table 7 Meteorological factors.

Maximum temperature, °Centigrade
Minimum temperature, °Centigrade
Sunshine hours
Global radiation, MegaJoules m^{-2}
Diffuse radiation, MegaJoules m^{-2}
Percentage relative humidity
Rainfall, millimetres
Pressure, millibars
Windspeed, $m\ s^{-1}$

Several analyses were conducted to establish the relationship of the airspora to meteorological factors. The first group of tests involved comparison of current airspora with current meteorological conditions. These are termed current analyses. The second group compared current airspora to past meteorological conditions. These are the time series analyses.

4.2.1 Current analyses

First, annual distribution plots of the airspora were compared with plots of meteorological data (Appendix 1).

Second, simple correlation analysis tested correspondence between meteorological data and airspora (Appendix 2). Data sets for the two years were combined consecutively to increase sample size. The program Statgraphics (STSC 1987) was used to establish Pearson's correlation coefficients on normalised data. Correlation coefficients were significant at the five percent level of confidence or less.

Third, stepwise multiple regression analysis (STSC 1987) (Appendix 3) established parameters significant for forecasting high pollen and spore days. Pollen and spores were the dependent variables, and meteorological factors were the independent variables or predictors. The program introduced and deleted independent variables one at a time until only those significant at the 0.05 level of probability were in the model. The selection of independent variables used the F-test as a criterion, based on the Mean Standard Error (MSE).

The diagnostics on which decisions were made for model selection were the residual plots and the Normal probability plots. The best models at both sites were obtained when the square roots of the dependent variables were used. Untransformed data showed non-constancy of variance in that the residual variance increased with predicted values. Similarly the Normal probability plots showed significant deviations from Normality. Selecting the square root transformations helped to stabilise the variance, made the data more Normal and gave better R^2 values.

Initial multiple regression analysis suggested a seasonal indicator to be an appropriate addition to the suite of independent variables.

The seasonal indicator was entered as a bimodal variable. Zero (0) was designated as 'out of season' and one (1) as 'in season'. The pollen season was considered to commence when the pollen count first registered 10 and ended on the last count of 10. The spore season was considered from the first to the last count of 5000 (all counts in numbers m^{-3} of air). These counts were somewhat arbitrary but were selected because they coincided with an escalation in both pollen and spores.

Finally, meteorological data of Johannesburg and Pretoria were compared by correlation analysis (Appendix 4). Correlation coefficients were similarly established between pairs of meteorological factors at Pretoria (Appendix 5) (STSC 1987).

4.2.2 Time series analysis

Time series analysis (cross-correlation) (STSC 1987) investigated the influence of weather periods antecedent to subsequent airspora seasons. The analysis estimated the correlation between one time series, pollen or spores, at time t and a second time series, the meteorological variable, at time t - k as a function of the lag or time differential k. This determined whether the meteorological parameter led pollen and spore output.

The time series analysis provided lag plots for Johannesburg and Pretoria (Appendix 6). Each lag corresponded to a ten-day period. Only the left hand side of each lag plot was significant, as positive lags were of no consequence in this study. I wished only to establish whether meteorological factors led airspora output, and not vice versa.

4.3 Results

a. Current analyses

4.3.1 Annual distribution plots (Appendix 1)

Annual distribution plots showed no appreciable differences between pressure, relative humidity and wind direction at the three different times of day, so that these factors were considered on a daily basis only.

Grass pollen

Grass pollen matched temperature most closely. Sunshine in contrast did not show a strong relation to pollen. The annual distribution curves for sunshine at both sites were very sporadic and if anything, there was a slight negative relationship to pollen. This was due to rainy days when sunshine hours were shortened.

Lower radiation (both global and diffuse) and rainfall in winter matched pollen fairly well. In the rainy summer season pollen remained positively related to radiation, but in general became negatively related to rain, eg beginning of March 1987 in Pretoria. This pattern was not consistent, however. There were occasions when pollen and rain were positively matched, eg beginning of

December, same year, same site.

Relative humidity increased slightly in summer so that there was marginal matching with pollen. In Pretoria relative humidity was more variable, so that the pattern was more obscure than in Johannesburg.

Increased winter pressure was negatively matched to pollen. In Pretoria during the first half of 1987 pressure peaked at mid-month and dropped at month-end. The decreases in pressure were related to rainy spells.

Low windspeeds in winter matched pollen. Windspeeds were greatest in spring but this was before the start of the grass season. In Pretoria during the first quarter of 1988 windspeeds were strong, matching those of the traditionally windy months August and September. This produced high correspondence with pollen at the time but as it was an unusual occurrence, the relationship was probably coincidental.

Fungal spores

Low winter spore counts reflected decreased temperature and solar radiation. The spore curves did not follow spring and early summer warming. Johannesburg showed an upward trend in spore production coinciding with warm late summer temperatures. In Pretoria spore numbers were high earlier in the season, corresponding to mid-summer temperature highs. The pattern was not consistent though, there was a sharp fall in the spore count at the beginning of February when temperatures were still very high.

The relationship between rainfall and spores was obscure. There were several rainy periods that matched high spore counts but there were also periods of low rainfall and high spore numbers.

There was no pattern between relative humidity and spores, with relative humidity exhibiting less seasonality than spores.

The general trend of slightly lower summer pressures corresponded with high spore counts, especially in late summer. However, the unusual Pretoria pressures of 1987 had no match in the spore curve.

In Johannesburg high spore counts were accompanied by low windspeeds and vice versa. In Pretoria mid-January of 1988 confirmed this trend, when the unseasonally high late summer winds mentioned above accompanied a dramatic decrease in spore count. However, a subsequent marked spore decrease in early March and similar decreases in 1987 did not occur in concert with high winds, so that the relationship with wind may only have existed during the spore season. Once the spore season had ended, windspeeds would have been irrelevant.

4.3.2 Correlation analysis

Correlation coefficients showed the following relationships

(Appendix 2):

1. Grass pollen was positively correlated with both maximum and minimum temperatures. The correlation was greater in Pretoria than Johannesburg. Spores showed consistent fair positive correlation with temperature.

2. Grass pollen showed fair positive correlation with rain. There was low positive correlation between spores and rainfall.

3. Neither grass pollen nor spores were correlated with sunshine hours.

4. Grass pollen was positively correlated with radiation whereas spores were not.

5. For grass pollen relative humidity showed greater positive correlation at 14h00 and 20h00 than at 8h00 although the correlation coefficient was never very high. The pattern for spores was similar.

6. Windspeed produced anomolous results. For grass pollen correlations fluctuated from positive to negative through the day, without being significant. Spores were not significantly correlated with windspeed in Pretoria. In Johannesburg there was reasonable negative correlation at all times.

4.3.3 Stepwise multiple regression analysis

The analysis is detailed in Appendix 3, where model fitting results, residual plots and Normal probability plots are given. The Normal probability plots of the regression residuals generally fell on a straight line. A deviation from this trend was seen in the plot of grass pollen in Johannesburg, where two outliers occurred.

Table 8 gives the prediction equations and adjusted R^2 values for grass pollen and fungal spores, resulting from the multiple regression analysis. The seasonal indicator entered all models except that of grass pollen in Pretoria.

In Johannesburg negative values for pressure and windspeed at 20h00 were most significant in forecasting high fungal spore counts. In Pretoria spores were positively affected by rain.

Grass pollen in Johannesburg was affected mainly by rain and sunhours.

Grass pollen in Pretoria was negatively influenced by windspeed at 14h00, and positively influenced by minimum temperature.

An analysis of individual correlations will not necessarily indicate the variables that will be included in a regression equation. This is caused by inter-correlation between the predictive variables themselves. Appendix 5 shows a correlation coefficient of 0.93 for Pretoria's maximum and minimum temperatures.

Table 8 Prediction equations derived from stepwise multiple regression analysis.

Johannesburg grass pollen:

$\sqrt{\text{Grass pollen}} = -5.03 + 0.05\ Rn + 0.66\ S + 3.32\ SI$

S.D. of prediction error = 2.26

$R^2 = 0.466$

(Average $\sqrt{\text{Grass pollen}}$ = 5.8)

Johannesburg fungal spores:

$\sqrt{\text{Spores}} = 1213.53 - 1.45\ Pat20 - 3.95\ WSat20 + 42.11\ SI$

S.D. of prediction error = 10.69

$R^2 = 0.787$

(Average $\sqrt{\text{Spores}}$ = 87.6)

Pretoria grass pollen:

$\sqrt{\text{Grass pollen}} = 2.40 - 0.94\ WSat14 + 0.41\ MinT$

S.D. of prediction error = 2.20

$R^2 = 0.513$

(Average $\sqrt{\text{Grass pollen}}$ = 6.9)

Pretoria fungal spores:

$\sqrt{\text{Spores}} = 35.24 + 0.46\ Rn + 59.95\ SI$

S.D. of prediction error = 26.89

$R^2 = 0.558$

(Average $\sqrt{\text{Spores}}$ = 108.3)

Where Rn = rain,
S = sunshine,
Pat20 = pressure at 20h00,
WSat14 = windspeed at 14h00,
WSat20 = windspeed at 20h00,
MinT = minimum temperature,
SI = seasonal indicator,
S.D. = standard deviation.

Individually these factors also correlated well with grass in Pretoria. The correlation coefficients were 0.64 and 0.63 (Appendix 2). Consequently the regression analysis selected only one of these two variables, ie minimum temperature.

b. Time series analysis (Appendix 6)

Both grass pollen and fungal spores showed significant correlations to rain and both maximum and minimum temperatures. The pattern of lag period correlation for maximum and minimum temperatures was identical, with similarly matched correlation coefficients. Therefore, only one of these two, maximum temperature, was considered in this analysis.

..ass pollen

In both Johannesburg and Pretoria temperature showed no lag period correlation. The best correlations (0.50 and 0.64 respectively) remained at lag 0, which was the time of sampling. The range of negative correlations at lag periods -9 to -23 simply reflected seasonal temperature patterns, these lags coinciding with the colder months (each lag corresponding to a ten-day time period).

Lags for rain also showed the seasonal influence of dry, cold months. There were additional positive relationships at lags of two to three months. In Johannesburg at lag period -7 and in Pretoria at lag -8 the highest correlations were found (0.37 and 0.40 respectively), so that grass pollen at any time was correlated with rainfall two to three months previously.

Fungal spores

Maximum temperature again produced a seasonal lag pattern, but the best correlation occurred between spores at present and temperatures six lags previously, ie exactly two months earlier. Correlation coefficients were 0.50 in Pretoria and 0.62 in Johannesburg.

The lag pattern for rain was more complicated, with fair correlation at lags -5 and -11. Correlation coefficients were 0.40 and 0.38 in Johannesburg and 0.31 and 0.39 in Pretoria.

4.3.4 Summary of results

a. Current analyses

Annual distribution plots

For grass pollen the most significant factors were maximum and minimum temperatures. The relationships were always positive. For spores the primary factor was windspeed, with high spore counts corresponding to low windspeeds.

Correlation analysis

Maximum and minimum temperatures once again emerged as the only significant factors corresponding with grass pollen, again with a positive relationship. There was no factor that correlated significantly with fungal spores.

Stepwise multiple regression analysis

Grass pollen in Johannesburg was influenced positively by rain and sunshine, while grass pollen in Pretoria was related positively to temperature and negatively to windspeed at 14h00. Spores in Johannesburg were related negatively to pressure and windspeed at 20h00, whereas in Pretoria there was a positive relationship to rain.

b. Time series analysis

For both grass pollen and fungal spores temperature was the most significant factor, but the lag periods differed. Current temperature was most highly correlated with current grass pollen, while temperature two months previously was most highly correlated with current fungal spores. Rain two to three months previously showed some relationship to both grass pollen and spores, but the correlations were not high.

4.4 Discussion

The results of the current analyses do not show total consistency, but certain trends recur. All three analyses indicated that temperature was an important factor in grass pollen incidence. The only exception was the regression analysis for Johannesburg, where temperature failed to enter the final model.

For fungal spores there was less consistency among the analyses. Only negative correspondence to windspeed showed any agreement.

All current analyses showed a noticeable variation between Johannesburg and Pretoria in the relationship of meteorological factors to the airspora.

Conversely, the time series analysis produced comparable results for the two cities. There were no significant lag period correlations between grass pollen and temperature. Once again the best relationship was found between current pollen and temperature. Rain two months previously was also positively correlated with grass pollen, but not as strongly as current temperature.

Fungal spores were positively related to both temperature and rain two months previously. A second positive correlation occurred between spores and rain four months previously.

4.4.1 Current analyses

The relationship of grass pollen to temperature was not demonstrated in similar studies from the northern hemisphere. Windspeed was a factor that appeared significant in several studies. Ljungkvist *et al* (1977) pointed out that windspeed could have opposing effects when measuring total atmospheric pollen. For example, strong winds would reduce pollen counts by sweeping the air, simultaneously whirling up grains that have previously been deposited on the ground. McDonald (1980) reported increased pollen concentrations following increased windspeed, but this correlation seemed to hold only in a year of high pollen concentration. Bringfelt *et al* (1982) found that grass pollen increased with windspeed at midday in Stockholm, but pointed out that mechanical effects may have been responsible. Windspeed is probably a meteorological factor that is regionally specific. One would expect the windspeeds of Stockholm's maritime airmass to behave differently to those of the continental airmass of the PWV.

Rainfall has also been mentioned as a controlling factor in northern hemisphere atmospheric pollen. In Galway Ireland, McDonald (1980) reported that high rainfall depressed pollen dispersal. However, in Ireland several days' continuous rain is common and quite different to conditions in the Transvaal. In the winter rainfall Cape Town region, Hawke and Meadows (1989) detected no significant relationship between rain and airspora, but found that troughs in airspora concentrations occurred after wet spells. Clearly the relationship is complex, and varies according to climate. The type of rainfall in the PWV probably complicates the relationship as well. The PWV experiences a variety of rain producing summer synoptic situations (Tyson 1986). In terms of pollen liberation and dispersal, these systems can be divided into two categories.

The first is typified by short-lived rainy spells often occurring daily, especially in the afternoons. The relationship to pollen will be positive as showers occur after peak pollen emission of early morning anthesis. In the second scenario which is less frequent, rainfall is more widespread and lasts for several days so that anthesis is retarded. The relationship to atmospheric pollen at such times will be negative.

The sunshine pattern follows a similar one to that of rainfall. The south Atlantic high pressure cell which is habitually situated over the sub-continent is responsible for extended sunny periods throughout the year. The general pattern of sunny days in the PWV, regardless of season, would exclude meaningful comparison with seasonal atmospheric pollen.

The greater uncertainty in the analyses of fungal spores has been confirmed by studies in other parts of the world, where spore differences between sites close to each other have been reported by several workers. Rubulis (1983) attributed such variability in Sweden to localised conditions. In two stations in south-western Germany daily averages of *Cladosporium* varied between 4 500 and 14 000 spores m^{-3} air (Grosse-Brauckmann & Stix 1968). Frinking (1977) highlighted the influence of rain and radiation on spores, and also the complex relationship between spores and relative humidity. However his studies spanned a much smaller time scale so that the results are not comparible to this study.

These inconsistencies indicate that fungal spores were very sensitive to meteorological conditions, and that very high resolution analysis is required, possible on a time scale of hours. This was confirmed in that observations of the Burkard strips in this study showed counts to vary considerably, both from day to day and frequently hourly. The response of the airspora to the micro-environment was extremely sensitive. Increases in spore production were sporadic and explosive, in contrast to most meteorological conditions which tended to increase linearly. Once atmospheric spores were detected, the increase was rapid. These sharp increases were most noticeable at the start of the spore season. A similar situation was found with grass pollen, although the pattern was not as clear.

This sudden escalation and decline in pollen and spore production lead to the decision to transform data to the square root form in the multiple regression analysis, as explained previously. The fact that the Normal probability plots of the regression residuals generally fell on a straight line (Appendix 3) confirms the approximate Normality of the residuals and also supports the appropriateness of the square root transformation. An appreciable deviation from a straight line in the Normal plot usually indicates some outlying value or values. There was such a slight tendency in the grass pollen plot for Johannesburg where two outliers could be identified. These outliers represented unusually high pollen values, and were most likely attributable to developmental or physiological factors mentioned above. The net result in terms of forecasts is that the model for Johannesburg grass pollen will tend to under-estimate atmospheric content if such uncommonly high counts occur in the future.

The seasonal indicator was included in the multiple regression analysis also as a result of the sudden start and close of both pollen and spore seasons. The inclusion of the indicator in all models except that of grass pollen in Pretoria was to be expected as grass pollen was less seasonal in Pretoria than Johannesburg, as was confirmed by the pollen calendars (Figures 3 & 4). Higher temperatures, extended flowering periods and fewer frost days in Pretoria were factors contributing to weaker seasonality there.

The seasonal indicator was of most importance for fungal spores in both Johannesburg and Pretoria, indicating the strong seasonality of these organisms when a cut-off point of 5000 spores m^{-3} is used.

A count of 5000 spores m^{-3} was higher than the 3000 quoted by Bagni *et al* (1977) as the threshold value for clinical significance of *Cladosporium*. Total fungal spore count was used in the PWV, where *Cladosporium* comprised 59.8% (Figure 7). Thus 5000 seemed reasonable when considering an undifferentiated spore sample.

As far as pollen is concerned, Driessen *et al* (1989) pointed out that there was no consensus as to the start of the season, with a variety of methods used to delimit the season. Most of these were retrospective, based on the entire season's output. When producing a pollen forecast, data for the season ahead are not available. In addition Strandhede and Wihl (1981) reported that physicians from the Nordic countries adopted a symptom-related scale for pollen bulletins. This scale gave values of 10 grass pollen grains m^{-3} as the cut-off between low and moderate discomfort for allergy sufferers. Therefore, 10 was adopted in this study for delimiting the start and end of the grass pollen season.

When forecasting high risk days, the R^2 values give the percentages of the airspora which were explained by the predictors selected. A regression analysis of this nature makes the assumption that the dependent variable, pollen or spores, is dependent on the independent variable, meteorological factors. This is not necessarily the case as cautioned by Mäkinen (1977). Physiology and phenology of the plant play a major role in the occurrence of the airspora.

Bearing in mind this caveat, the values were more encouraging for forecasting spores than pollen. This indicates that spores were more closely tied to atmospheric conditions than pollen, where other factors appeared dominant. It is also possible that a two-year data base was not sufficient for adequate identification of meteorological factors.

There was a noticeable variation between the models for both grass pollen and spores for Johannesburg and Pretoria. The correlation analysis of meteorological factors at these two cities (Appendix 4) showed that apart from the three daily pressure readings, all factors were significantly highly correlated. Since pressure only entered into one of the models (at 20h00 for fungal spores in Johannesburg), variability between the two sites was not due to differences in meteorology. The major cause was probably the different climatic regions of the cities. Although they are located only seventy kilometres apart, it appears that the grass taxa occurring in the two vegetation zones, Bankenveld and Tropical Bush and Savanna Type, were responding differently to very similar meteorological conditions. Variations in the pollen calendars (Figures 3 & 4) reinforces this opinion.

4.4.2 Time series analysis

The results for grass pollen, where current temperature was the only significant factor related to current pollen, did not conform with northern hemisphere studies. In such studies generally positive relationships were found between spring temperatures and summer pollen (Davies & Smith 1973, Bringfelt *et al* 1982, Koivikko *et al* (1986). However studies where snow and spring temperatures below 0°C are regular occurrences cannot be expected to have a parallel in South Africa. Goldberg *et al* (1988), working in Denmark also found a correspondence between late spring/early summer temperature and grass pollen. They attributed an anomolous year to unusual weather in that particular year.

The relationship that was seen between rain and grass pollen was not striking, but nevertheless a pattern was obvious. Translated into flowering seasons, this relationship meant that good spring rains produced high pollen counts in the early summer and that good summer rains produced high pollen counts in early autumn.

In New Jersey Reiss and Kostic (1976) reported a correlation between spring rain and summer pollen similar to that of the

PWV. As Reiss and Kostic (1976) were working on *Ambrosia* pollen the comparison is not entirely valid.

The time series analysis for fungal spores showed that high spore counts in any ten-day period corresponded best with high temperatures two months earlier, and conversely low temperatures were followed by low spore counts two months later. The latter scenario is easier to explain, in that low temperatures result in the death and gradual unavailability of parasitic hosts, so that a two-month delay is feasible. The relationship between high readings is not clear. There was probably a complex interaction between high temperatures, spores and some other parameter, possibly rain. Indeed, the lag period in rain occurring fifty days prior to high spore counts may have had some significance when considered in tandem with the two-month temperature lag. If high temperatures and good rains occurred together, high spore counts were measured approximately two months later. Such conditions would have stimulated host development, so that the scenario seems likely. The fifty-day rainfall lag was therefore probably associated with the first flush of plant growth after winter. The earlier rain lag, occurring approximately four months prior to high spore counts, indicated the relationship of spring rain to peak summmer plant abundance. Both situations would have favoured fungal growth. This pattern occurring at both sites supports this explanation.

4.5 Summary and conclusions

1. The above analyses indicate that current temperature was the

the most important meteorological factor controlling current atmospheric grass pollen, with a positive relationship.

2. Spring rain had an impact on summer grass pollen, but the relationship was not as marked as that of temperature. This relationship was also positive.

3. Fungal spores were negatively related to current windspeeds, and positively to both temperature and rain which occurred two months previously. However, there was poorer agreement between analyses of fungal spores than pollen. Spores appeared very sensitive to meteorological conditions in the immediate environment, indicating that very high resolution analysis is required.

4. The current analyses showed considerable variation between grass pollen in Johannesburg and Pretoria. However, such a variation was not apparent in the time series analysis. Since daily meteorological factors between the two cities correlated highly, the cause of this variability must lie elsewhere. It is suggested that the native grasses of the two different vegetation regions responded differently to the different long-term climatic conditions of the two cities. The fact that the time-series analysis did not show the same variability as the 'current' analyses supports this suggestion, as conditions that occurred earlier conceivable blended with the long-term, overall climate.

Chapter 5

Pollen as an Indicator of Vegetation and Land-use

5.1 Introduction

Numerous studies in this country have offered palaeoclimatic interpretations based on fossil pollen assemblages (Coetzee 1987, Scott 1989a 1989b). These interpretations were derived from pollen diagrams. However, it is not clear whether pollen diagrams in fact reflect the vegetation. To describe this relationship various numerical methods have been used, relating soil-derived pollen spectra to vegetation (summarised in Birks & Gordon 1985). This chapter compares both surface and subsurface pollen to atmospheric pollen in the PWV, and examines the relationship of each to vegetation and climate. Pollen as an indicator of land-use is discussed.

5.2 Methods

Chapter 1.8.1 details preparation procedures for pollen used in this analysis. Atmospheric pollen data (A) from the gravity samplers, and surface (S) and subsurface (C = core) pollen samples derived from soil samples at each site were used. Vegetation data (V) were derived from the vegetation quadrats at each site (Chapter 1.8.2). Only the native components of pollen and vegetation were considered, as this would have been the relevant relationship in a fossil sequence.

A pollen diagram was constructed to compare A, S, C and V samples for each site. The pollen diagram (Figure 9) reflects the Total Pollen Composition, which was composed of the Pollen Sum, and pollen derived from plants of damp habitats. Plants of damp habitats were excluded from the Pollen Sum for consistency, as they occurred infrequently only as localised elements in soil samples of the marshy sites (4, 7, 10 and 11).

The Pollen Sum included the following categories: arboreal pollen (AP), and non-arboreal pollen (NAP), and Unidentified (Table 9). For A samples, the Pollen Sum constituted the combined pollen count for 1987 and 1988, with each taxon expressed as a percentage of that total. Similarly pollen in S and C samples at each site were also expressed as a percentage of total pollen count, the Pollen Sum. For V samples, taxa were presented individually as percentages of the total vegetation at each site, as calculated in Chapter 1.8.2.

The category Unidentified referred to pollen in A, S and C samples, while in V samples, Unidentified included all vegetation present in percentages less than 0.001% of total vegetation.

The literature does not distinguish between South African anemophilous and entomophilous taxa. However, Robinson (personal communication 1989) suggested that of the taxa listed in Table 9, only *Celtis* and *Rhus* are extensively wind-pollinated.

Sites 2 and 8, the urban localities, were excluded from this analysis as there were no suitable undisturbed areas for soil sampling in the vicinity.

Simple correspondence analysis (CA) using the program SIMCA (Greenacre 1986) was performed on the percentage data of the

Pollen Sum. CA is usually applied to raw data but in this case percentages were used as the data were not equivalent. This was because total pollen varied among samples although the count was always as close to 250 grains as possible. All data were multiplied by 1000 so that small percentages could be shown.

CA depicts relations within a two way data matrix, providing both numerical and graphical comparisons of the relationships between the matrices. These relationships are multidimensional. However, the aim of the technique is data reduction, so that the maximum information possible is given in a few dimensions. The graphical display shows the relationships between the two most important axes.

In the interpretation of the graphs the following rules apply, subject to confirmation by reference to the numerical output.

1. Importance of a point increases with distance from the origin.

2. The closer a point lies to an axis, the greater the correlation with that axis.

3. Points that lie on similar radii from the origin are positively correlated; points that lie at 90° to one another are uncorrelated; points that lie at 180° to one another are negatively correlated.

In order to test the feasibility of inferring past vegetation from a fossil pollen spectrum, data for a possible null model were constructed. If there had been a good match between A, S, C and V samples, data would have shown the same relative abundance within taxa between these four categories. CA was first performed on the null data alone. Then the real data for site 1 were projected as supplementary points onto the display of the null model. Supplementary points are illustrative, and do not determine the display of the original or active points. Rows (taxa) and columns (categories) were projected separately as supplementary points.

To examine the relationship between pollen and climatic factors, the following comparisons were made. First, annual temperature and rainfall data for all sampling sites were averaged for the study period. Those averages were then compared to the long-term annual average temperatures and rainfall for Johannesburg and Pretoria.

A second comparison of finer resolution was made between rainfall and grass pollen at sampling sites, calculated on a monthly basis.

To examine the relationship between pollen and land-use, data from atmospheric samples were used. Total alien pollen for 1987-1988 was expressed as a percentage of total pollen at each site.

5.3 Results

5.3.1 Correspondence analysis

The data matrices give the taxa of Table 9 in rows and the categories A, S, C and V in columns. Table 10 gives the CA for site 1. Data for other sites are in Appendix 8. Data and the CA for the null model are shown in Table 11, and the graphs are displayed in Figures 11a and 11b. Figures 12a and 12b compare the data of the null model to site 1.

Results of the CA of the sampling sites indicated that on the whole, V samples were negatively correlated with A, S and C samples, and these three were either weakly correlated, or not correlated at all, with one another. The taxa *Rhus*, *Celtis* and Poaceae made the greatest contribution to the analyses. Grass was well correlated with vegetation, as was a group of insect-pollinated trees. Wind-pollinated trees were not correlated with vegetation, and neither were insect-pollinated non-arboreal taxa. These last two groups were generally correlated with A samples.

Graphical output for site 1 is displayed in Figure 10. Other graphs are in Appendix 9. These displays show that the overall percentages of principal inertias were well represented in two dimensions, in most cases accounting for at least 90% and in all cases for more than 80% of the variation. This means that the plots of CA are almost exact displays of the profiles at each site.

As the data outputs for all sites were broadly similar, site 1 is discussed as representative. This is followed by remarks pertinent to individual sites.

Table 9 Taxa in CA and pollen diagram.

Arboreal taxa	Non-arboreal taxa	Taxa of damp habitats
1 *Acacia*	26 Acanthaceae	57 *Anthoceros*
2 *Bequertiodendron magaliesmontanum*	27 Aizoaceae	58 Bryophyte spore
3 *Buddleja*	28 *Aloe*	59 Cyperaceae
4 *Canthium*	29 *Anthospermum*	60 *Hydrocotyle*
5 *Carissa*	30 *Artemisia afra*	61 *Ludwigia*
6 *Celtis africana*	31 *Cannabis*	62 *Nympheae*
7 *Combretum*	32 Chenopodiaceae/ Amaranthaceae	63 *Polygonum*
8 *Cussonia*	33 Compositae	64 Potamogetonaceae
9 *Dias cotinifolia*	34 Convolvulaceae	65 *Riccia*
10 *Dichrostachys cinerea*	35 *Crassula*	66 Trilete spore
11 *Diospyros*	36 Cruciferae	67 *Typha*
12 *Dombeya rotundifolia*	37 *Erica*	
13 *Ehretia rigida*	38 Euphorbiaceae	
14 *Euclea*	39 Labiatae	
15 *Grewia*	40 Liliaceae	
16 *Halleria lucida*	41 Malvaceae	
17 *Heteromorpha trifoliata*	42 *Myrothamnus flabellifolia*	
18 *Hypericum*	43 *Oenothera*	
19 *Maytenus*	44 *Plantago*	
20 *Olea europeae*	45 Polypodiaceae	
21 *Pappea capensis*	46 *Scabiosa*	
22 Proteaceae	47 *Selago*	
23 Rhamnaceae	48 *Sida*	
24 *Rhus*	49 Solanaceae	
25 *Zizyphus mucronata*	50 *Stoebe vulgaris*	
	51 *Taraxacum*	
	52 *Tribulus*	
	53 Umbelliferae	
	54 *Vernonia*	
	55 Poaceae	
	56 Unidentified	

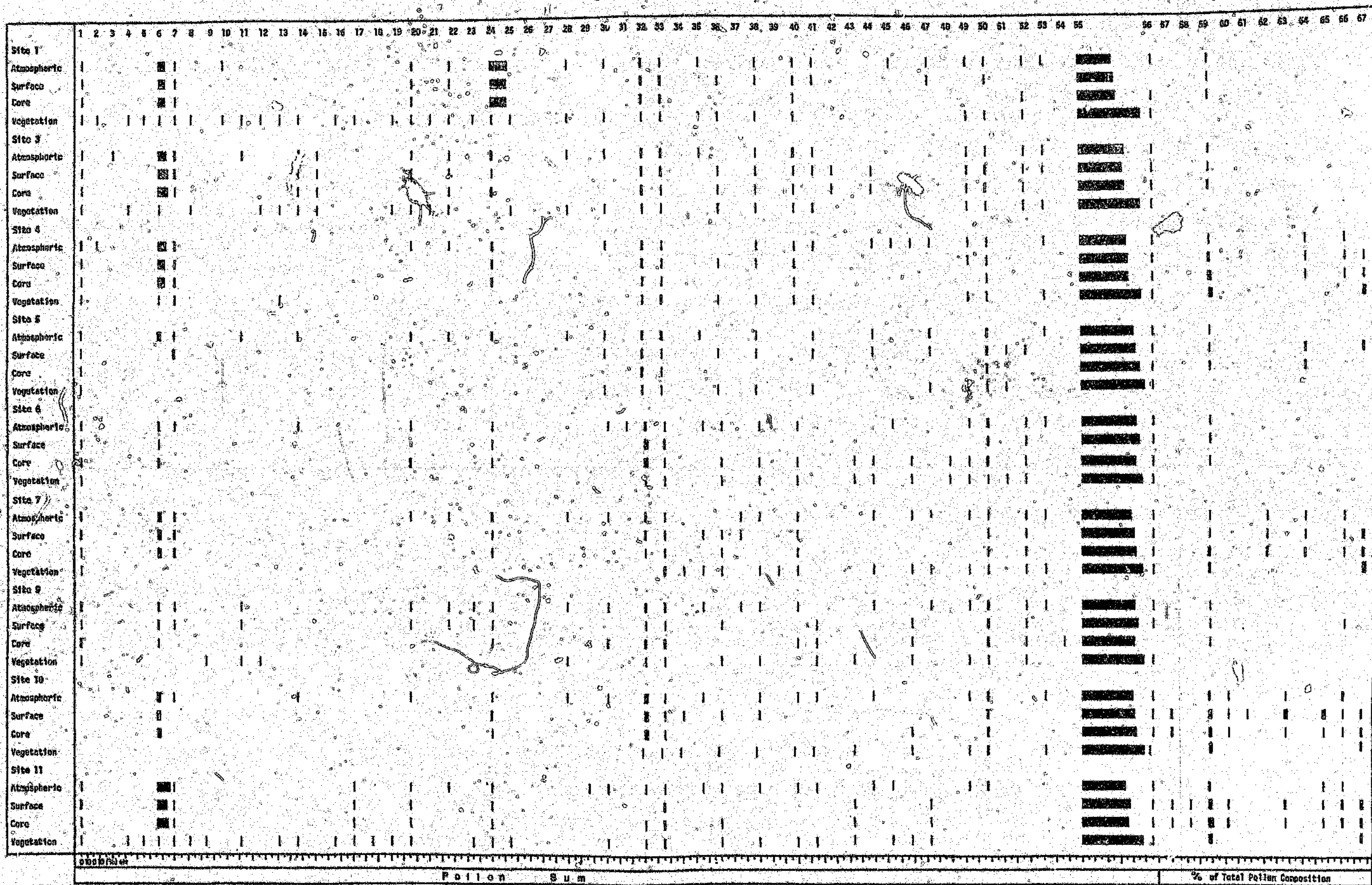


Figure 9 Pollen diagram.

Table 10 CA of site 1

(all percentage data have been multiplied by 1000, eg, in the first column of the last row, taxon 55: 53458 = 53.458%).

Input
37 4 0 2
Output
1 1 1 1 1
Columns
A,S,C,V
Template
1111
Graphs
12002 3311
Data

1	497	560	340	212
2	0	0	0	5
4	0	0	0	19
5	0	0	0	5
6	9744	10640	9510	147
7	1261	910	167	15
8	0	0	0	56
10	38	0	0	10
11	0	0	0	58
12	0	0	0	33
13	0	0	0	44
14	0	0	0	47
16	0	0	0	4
17	0	0	0	26
19	0	0	0	18
20	1032	980	650	18
21	0	0	0	25
22	76	20	0	12
23	0	0	0	45
24	28009	25960	24840	251
25	0	0	0	37
20	267	0	0	1
30	38	0	0	1
32	2598	1940	1613	2
33	1223	2500	3226	2
35	115	0	0	2
36	0	80	0	1
38	38	500	0	2
40	344	250	320	2
41	76	100	0	0
45	76	0	0	0
47	76	500	0	0
49	76	0	0	2
50	650	500	0	7
52	115	0	610	31
53	191	0	0	0
55	53458	54560	58725	98862

Inertias and percentages of inertia

1	0.165194	87.70%	[[
2	0.013982	7.42%	[[[[
3	0.009177	4.87%	[[[
	0.188353		

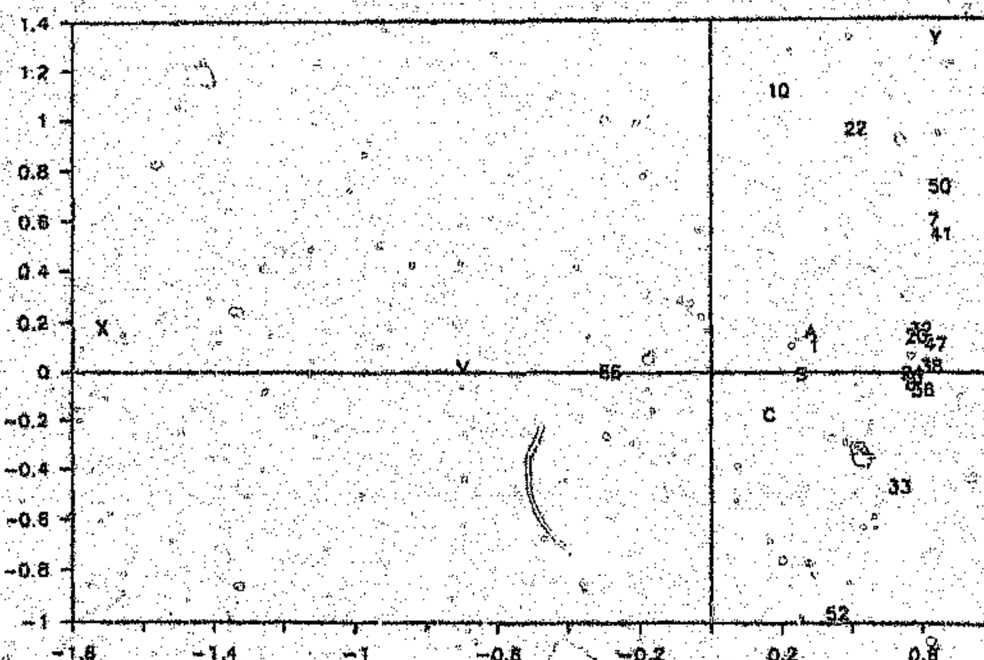
Table 10 CA of site 1(continued).

Row Contributions

I	NAME	QLT	MAS	INR	k=1	COR	CTR	k=2	COR	CTR
1	1	841	4	2	291	740	2	107	101	3
2	2	999	0	0	-1722	988	0	179	11	0
3	4	999	0	1	-1722	988	1	179	11	0
4	5	999	0	0	-1722	988	0	179	11	0
5	6	996	75	129	566	989	145	-48	7	13
6	7	981	6	24	632	521	14	594	460	149
7	8	999	0	2	-1722	988	3	179	11	0
8	10	755	0	1	190	21	0	1111	734	11
9	11	999	0	2	-1722	988	3	179	11	0
10	12	999	0	1	-1722	988	1	179	11	0
11	13	999	0	2	-1722	988	2	179	11	0
12	14	999	0	2	-1722	988	2	179	11	0
13	16	999	0	0	-1722	988	0	179	11	0
14	17	999	0	1	-1722	988	1	179	11	0
15	19	999	0	1	-1722	988	1	179	11	0
16	20	988	7	13	582	933	14	141	55	10
17	21	999	0	1	-1722	988	1	179	11	[illegible]
18	22	935	0	2	413	146	0	960	789	18
19	23	999	0	2	-1722	988	2	179	11	0
20	24	977	198	344	572	977	392	-3	0	0
21	25	999	0	1	-1722	988	2	179	11	0
22	28	772	1	11	684	157	2	1351	615	88
23	30	770	0	1	631	142	0	1326	628	12
24	32	990	15	31	595	918	33	166	71	30
25	33	997	17	46	533	565	30	-466	431	270
26	35	771	0	4	651	148	1	1336	623	37
27	36	126	0	3	601	124	0	-75	2	0
28	38	160	1	18	626	160	3	24	0	0
29	40	921	2	4	568	920	4	-21	1	0
30	41	699	0	2	657	416	1	541	282	9
31	45	733	0	3	693	160	1	1356	613	25
32	47	201	1	16	638	196	4	111	6	1
33	49	770	0	3	631	142	0	1326	628	25
34	50	946	3	16	651	420	7	729	527	110
35	52	618	2	17	357	75	1	-962	544	125
36	53	773	0	8	693	160	1	1256	613	63
37	55	1000	664	284	-284	1000	324	1	0	0

Column Contributions

J	NAME	QLT	MAS	INR	k=1	COR	CTR	k=2	COR	CTR
1	A	944	250	148	282	713	120	160	231	460
2	S	734	250	119	256	733	99	-9	1	2
3	C	895	250	83	162	420	40	-172	475	531
4	V	1000	250	651	-700	999	741	21	1	8



where X = 2, 4, 5, 8, 11, 12, 13, 14, 16, 17, 19, 21, 23, 25
and Y = 28, 30, 35, 45, 49, 53

Figure 10 Graphical output of CA of site 1.

Table 11 CA of the null model.

Input
37 4 0 2
Output
1 1 1 1 1
Columns
AN SN CN VN
Template 1111
Graphs
12002 1010, 12002 0101, 12002 3011, 12002 0311
Data

		1 AN	2 SN	3 CN	4 VN	sum
1	1N	308	321	345	325	1299
2	2N	1	1	1	1	4
3	4N	19	21	20	20	80
4	5N	5	5	6	4	20
5	6N	5863	5863	5897	5987	23610
6	7N	864	873	853	813	3403
7	8N	49	51	50	47	197
8	10N	38	41	40	39	158
9	11N	61	58	60	59	238
10	12N	35	33	32	29	129
11	13N	44	45	46	42	177
12	14N	51	47	49	50	197
13	16N	4	5	3	4	16
14	17N	25	26	28	24	103
15	19N	18	19	17	18	72
16	20N	7645	7864	7986	8054	31549
17	21N	24	22	23	25	94
18	22N	75	76	74	79	304
19	23N	44	43	41	47	175
20	24N	16853	17243	16985	17134	68215
21	25N	40	42	39	40	161
22	28N	267	255	271	260	1053
23	30N	38	35	39	40	152
24	32N	1985	1897	1957	1987	7826
25	33N	1123	1234	1167	1176	4698
26	35N	115	120	116	121	472
27	36N	80	75	77	82	314
28	38N	467	498	432	465	1862
29	40N	234	254	265	287	1040
30	41N	100	105	79	89	373
31	45N	75	77	85	80	317
32	47N	76	82	78	80	316
33	49N	76	75	86	80	317
34	50N	456	432	476	453	1817
35	52N	115	120	124	118	477
36	53N	154	153	165	176	648
37	55N	62572	61892	62000	61662	248126
sum		99999	100003	100010	99997	400009

Inertias and percentages of interia

```
0.000088   53.97% [[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[
0.000055   33.54% [[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[
0.000020   12.49% [[[[[[[[[[[[[
________
0.000164
```

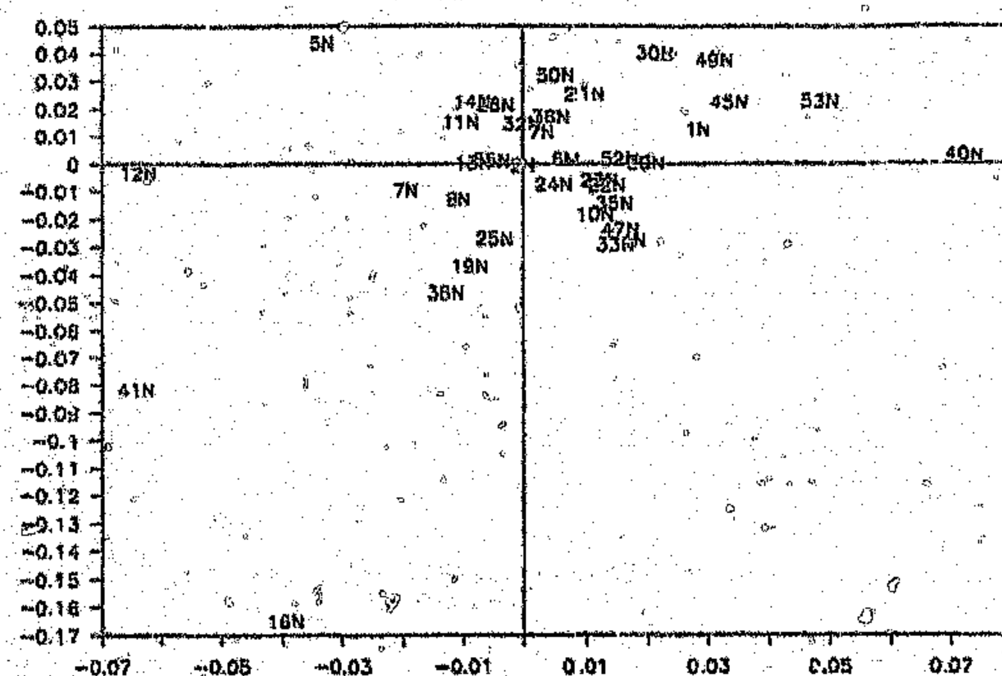
Table 11 CA of the null model (continued).

Row Contributions

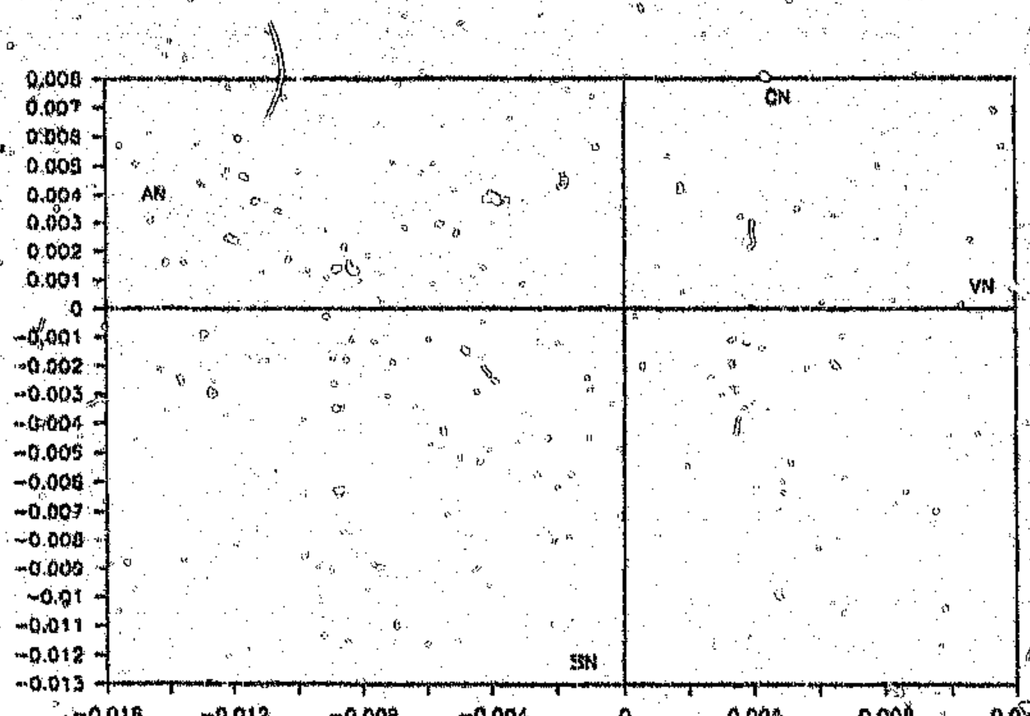
I	NAME	QLT	MAS	INR	k=1	COR	CTR	k=2	COR	CTR
1	1N	578	3	33	28	479	29	13	99	10
2	2N	%55158.4609375		0	01 -0	185	01	-0%54973.28515625		01
3	4N	865	0	2	18	249	1	-28	616	3
4	5N	151	0	6	-33	55	1	44	95	2
5	6N	665	59	27	7	628	31	2	36	3
6	7N	650	9	38	-19	523	36	-10	127	14
7	8N	318	0	3	-11	125	1	-13	193	2
8	10N	581	0	2	11	159	1	-18	422	2
9	11N	963	1	1	-10	302	1	15	661	3
10	12N	910	0	9	-64	908	15	-3	2	0
11	13N	61	0	3	-8	61	0	0	0	0
12	14N	636	0	3	-8	79	0	22	557	5
13	16N	923	0	8	-39	50	1	-165	873	20
14	17N	41	0	5	2	1	0	11	40	1
15	19N	936	0	2	-9	50	0	-37	886	4
16	20N	992	79	187	20	992	344	0	0	0
17	21N	324	0	3	10	42	0	25	282	3
18	22N	384	1	3	13	289	2	-8	95	1
19	23N	75	0	7	12	60	1	-6	15	0
20	24N	1066	171	78	5	336	49	-7	730	170
21	25N	1022	0	2	-5	30	0	-27	992	5
22	28N	869	3	9	-4	35	1	21	834	22
23	30N	848	0	6	21	185	2	40	663	11
24	32N	618	20	41	-0	0	0	15	618	76
25	33N	933	12	82	15	187	28	-29	746	181
26	35N	887	1	3	15	450	3	-14	437	4
27	36N	266	1	6	5	18	0	17	247	4
28	38N	925	5	72	-13	65	9	-47	859	183
29	40N	956	3	86	72	954	152	3	2	0
30	41N	927	1	66	-64	356	44	-82	571	118
31	45N	714	1	11	33	494	10	22	220	7
32	47N	1015	1	4	15	299	2	-24	715	8
33	49N	795	1	14	31	322	9	37	473	20
34	50N	899	5	33	5	24	1	32	876	85
35	52N	322	1	5	15	318	3	2	4	0
36	53N	855	2	33	48	699	43	23	155	15
37	55N	965	620	110	-5	893	183	1	72	24

Column Contributions

J	NAME	QLT	MAS	INR	k=1	COR	CTR	k=2	COR	CTR
1	A	971	250	355	-14	901	593	4	70	74
2	S	965	250	238	-1	9	4	-12	955	678
3	C	678	250	171	5	198	63	7	480	245
4	V	784	250	235	11	780	340	1	4	3



a taxa



b categories

Figure 11 Graphical output of CA of the null model.

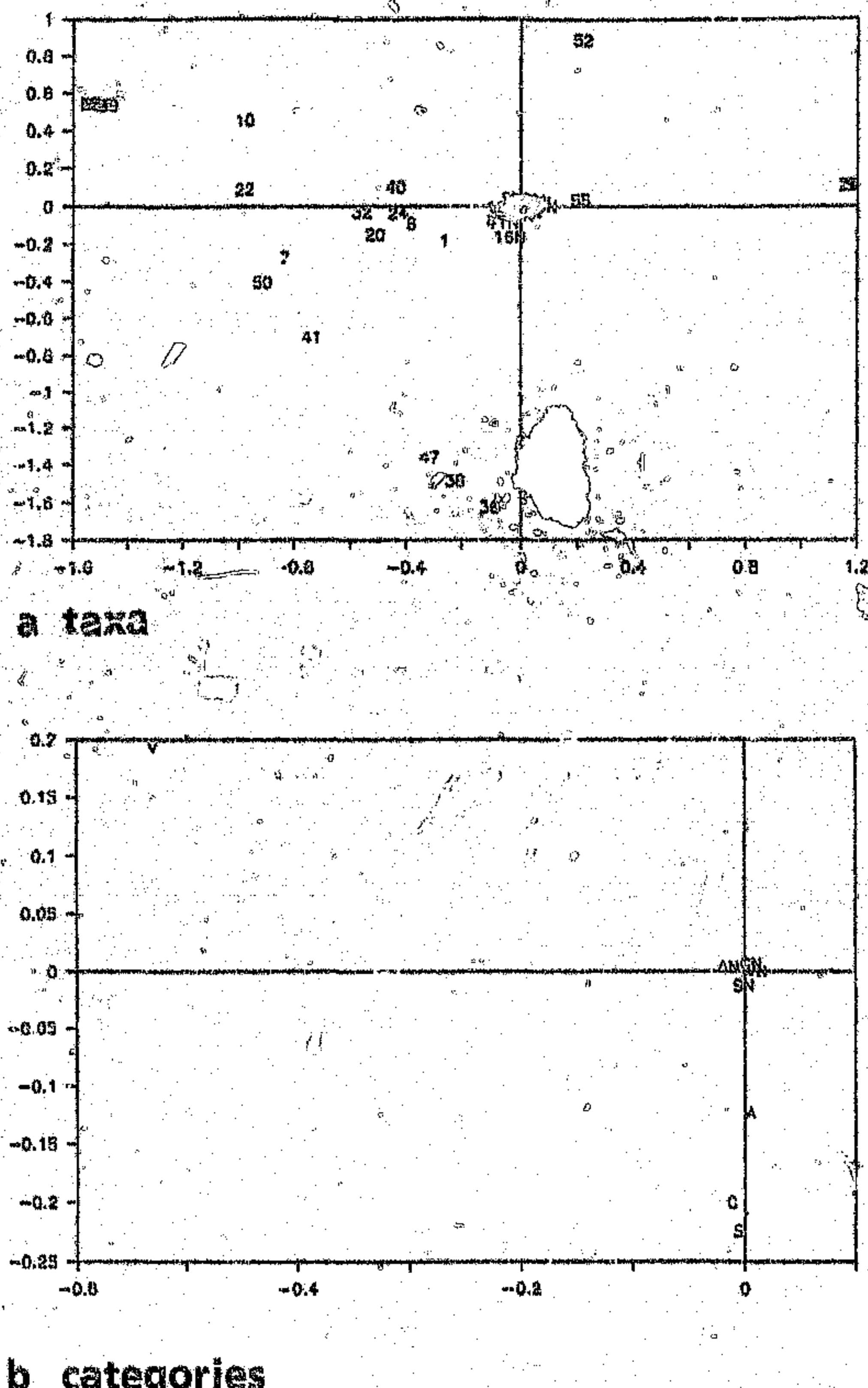


Figure 12 Real data displayed on CA of the null model.

Table 12 Average temperatures and rainfall for Johannesburg and Pretoria.

Pretoria sites, annual average temperature 1987/1988	17.7°C
Pretoria long-term annual average temperature	17.7°C
Johannesburg sites, annual average temperature 1987/1988	16.6°C
Johannesburg long-term annual average temperature	16.3°C
Pretoria sites, average total rainfall 1987/1988	709 mm
Pretoria long-term annual total rainfall	716 mm
Johannesburg sites, average total rainfall 1987/1988	797 mm
Johannesburg long-term annual total rainfall	811 mm

Table 13 Monthly rainfall data for sampling sites

(* = data unavailable,
£ = average for Johannesburg sites was assumed (61.4 mm),
%N = percentage of normal rainfall, measurement in mm).

	Site 1		Site 3				Site 4		Site 5			
	1987	1988	1987	%N	1988	%N	1987	1988	1987	%N	1988	%N
J	103.2	105.8	77.5	*	54.4	41	93.2	79.7	108.0	96	142.3	126
F	74.2	60.4	142.7	*	46.4	50	103.0	90.4	52.9	51	36.5	25
M	90.2	142.4	160.2	219	81.0	95	196.3	139.4	128.9	143	169.5	189
A	25.6	79.9	33.6	64	82.8	159	23.7	84.5	12.8	27	23.7	51
M	0	1.7	0		0.4	1	0.1	1.0	1.5	8	3.4	18
J	0	13.5	0		7.0	86	0	8.4	0		10.8	177
J	0	3.0	0		3.3	47	0	2.4	0		2.9	32
A	20.0	0	27.0	473	2.2	*	25.8	1.2	13.4	167	1.0	12
S	72.9	50.0	85.6	*	49.8	*	91.0	50.0	125.9	567	56.6	254
O	42.5	76.7	35.9	*	69.3	*	69.0	95.1	64.4	101	86.2	135
N	132.2	51.5	126.8	*	49.9	*	162.9	48.9	171.6	156	20.5	18
D	124.2	64.8	75.4	*	121.4	*	82.2	138.9	91.4	81	67.4	60
Σ	685.0	649.7	764.7		567.9		847.2	739.9	770.8		620.8	

	Site 6			Site 7				Sites 9 & 10		Site 11			
	1987	1988		1981	%N	1988	%N	1987	1988	1987	%N	1988	%N
J	134.2	126.5	97	99.0	67	51.2	34	110.1	175.2	120.0	97	88.0	71
F	84.3	70.5	74	57.5	80	40.1	37	161.9	38.0	45.5	51	51.5	51
M	219.2	130.1	161	264.8	312	91.2	197	131.0	160.6	62.7	91	110.0	126
A	9.2	48.0	87	5.0	8	49.7	87	14.7	21.4	20.1	30	6.8	16
M	0	1.5	8	0		1.0	6	1.0	2.6	0		0	
J	0.1	26.3	375	5.0	58	13.9	163	0	11.1	0		15.5	242
J	0	4.8	80	0		17.0	230	0	3.7	0		2.5	32
A	19.2	0.1	2	56.0	888	0		20.1	1.2	14.4	288	2.0	26
S	175.0	53.8	207	97.2	514	57.2	302	167.7	53.7	169 6	1246	51.3	253
O	69.5	79.3	110	69.0	102	65.2	96	42.6	90.4	£	£	152.0	245
N	200.2	69.1	52	168.5	141	79.5	66	136.3	71.1	181.8	155	63.5	54
D	107.8	127.8	121	166.2	146	123.6	108	132.9	141.4	72.3	62	42.2	36
Σ	1018.7	727.8		988.2		589.1		917.4	770.4	675.4 (11 mths)		585.6	

Table 14 Monthly grass pollen expressed as a percentage of annual total, 1987-1988.

	Site 1		Site 2		Site 3		Site 4		Site 5	
	1987	1988	1987	1988	1987	1988	1987	1988	1987	1988
J	28.8	14.5	31.5	30.2	34.7	19.6	21.2	26.0	25.3	29.7
F	20.2	12.8	27.0	12.9	36.1	5.2	25.0	6.5	24.6	4.6
M	8.0	15.9	0.8	21.7	9.4	26.3	12.6	14.3	0.0	12.7
A	1.9	15.4	0.7	9.7	2.0	11.9	2.0	14.3	2.0	8.1
M	4.0	4.4	1.1	1.5	5.2	2.6	3.0	2.2	2.7	4.3
J	0.8	1.3	2.0	0.9	1.4	1.0	1.0	1.7	0.9	1.6
J	0.8	0.4	1.1	0.3	0.4	0.0	0.6	0.4	0.7	0.0
A	0.3	7.9	0.7	2.4	0.6	3.6	0.3	1.7	0.2	3.5
S	0.4	7.5	1.1	4.1	0.2	2.6	0.1	6.9	0.1	2.7
O	7.0	5.3	5.1	8.2	1.4	7.2	1.8	4.3	1.3	5.4
N	13.5	6.2	8.7	2.4	4.8	5.7	15.0	17.8	16.2	23.0
D	14.4	8.4	20.2	5.9	6.0	14.4	17.5	3.9	26.0	4.3

	Site 6		Site 7		Site 8		Site 9		Site 10		Site 11	
	1987	1988	1987	1988	1987	1988	1987	1988	1987	1988	1987	1988
J	20.6	20.9	32.0	28.7	18.6	36.9	20.3	29.4	29.0	44.0	16.6	31.1
F	23.9	11.9	22.5	23.9	24.1	8.5	22.4	33.6	23.8	4.7	26.5	37.3
M	17.0	15.4	0.5	10.7	8.7	16.2	8.1	8.9	11.3	19.7	14.2	8.2
A	2.4	9.0	0.6	6.6	1.4	5.2	0.4	5.7	1.2	10.4	0.8	3.7
M	3.4	1.9	3.1	3.3	2.1	3.0	2.5	1.4	1.4	2.1	2.0	3.7
J	0.4	1.0	0.7	1.1	1.6	0.0	0.1	1.2	0.1	0.0	0.5	0.0
J	0.9	0.3	0.4	0.0	0.7	0.4	0.3	0.5	0.5	0.5	0.8	0.3
A	0.3	1.6	0.3	1.8	0.2	2.2	3.6	0.7	0.5	3.1	0.3	1.7
S	0.1	2.9	0.1	1.1	0.2	6.3	0.1	2.4	0.1	5.2	0.1	2.3
O	1.1	9.7	0.8	3.7	10.3	7.4	0.8	3.4	0.4	3.1	1.5	3.7
N	22.9	23.2	18.1	15.1	16.6	10.7	17.9	7.2	14.3	3.6	16.3	5.7
D	6.9	2.3	20.9	4.0	15.4	3.3	23.5	5.7	17.6	3.6	20.5	2.5

Table 15 Alien pollen expressed as a percentage of total atmospheric pollen, averaged for study period.

Site	% of Total
1	47.69
2	51.11
3	38.46
4	38.51
5	39.86
6	44.04
7	35.04
8	47.80
9	37.84
10	44.08
11	18.72

Site 1 (Table 10)

The first two axes contributed 95.12% to total inertia. In terms of taxa (rows), the quality of display in two dimensions (QLT) was high in all cases except for taxa 36 and 38 (Cruciferae and *Erica*). The greatest contributions to total inertia (INR) were made by taxa 6 (*Celtis*), 24 (*Rhus*) and 55 (Poaceae). Many taxa were highly correlated with the first axis (COR). However, they appeared to be insignificant, as determined by their low weights (MAS). This was confirmed by their low contributions to the first principal inertia (CTR). Only taxa 6 (*Celtis*), 24 (*Rhus*) and 55 (Poaceae) were meaningful.

Correlation (COR) with the second axis was good in several cases, and some taxa made contributions above average to the second principal inertia (CTR), so that these row points were meaningful. The taxa concerned were 28 (*Aloe*), 35 (*Crassula*), 50 (*Stoebe*), 52 (*Tribulus*) and 53 (Umbelliferae).

In terms of categories (columns), the quality of display in two dimensions (QLT) was very good, especially in the case of V, where maximum display was achieved. Consequently, V contributed the greatest proportion to total inertia (INR). The contribution to total inertia of A, S, C and V, individually, varied considerably. At the two extremes were V, contributing 65.1% and C, with a contribution of only 8.3%. Correlation with the first axis (COR) was high for three of the four categories, C showing only fair correlation.

Column contributions to the second axis (CTR) were above average for both A and C, but as the correlations with the second axis (COR) were not good, these column points were not meaningful.

Site 1 (Figure 10)

Atmospheric and core samples were tending towards zero correlation with each other. Surface samples were positively correlated with both these samples. Vegetation was negatively correlated with the other three categories.

There were many trees (shown collectively as X at extreme left of the first axis) that were highly positively correlated with vegetation, and with grass. These trees were negatively correlated with the other categories, seen by their almost 180° opposition to these categories. Conversely the two taxa *Rhus* and *Celtis* were negatively correlated with vegetation and positively with the other three categories. Grass was well correlated with vegetation, but correlation with the other three categories was negative.

A group of taxa (shown as Y) was well correlated with the atmospheric sample. This group, all non-arboreal taxa, showed fair correlation with the surface sample, zero correlation with the core sample, and almost total negative correlation with the vegetation sample.

Comparison of other sites with site 1 (Appendices 9 & 10)

Sites 3 and 4 were most similar to site 1 in terms of distribution of points in the plots. Thereafter scatter of individual points was slightly more varied, but all sites showed consistency in that vegetation contributed largely to total inertia, and that windpollinated trees dominated, as above. This was especially obvious in the case of *Celtis africana*. Many instances of outliers occurred eg at site 6 *Taraxacum*, seen at the far left of axis 1 in the plot for this site. However, these outliers appear insignificant, as evidenced by their low weights.

The plots show a shift in position of grass relative to the origin. As the sites moved from the savanna of Pretoria-north to the grasslands further south, grass moved closer to the origin, which would normally indicate that grass was becoming less important. However, as mentioned above, the numerical data must be taken into account, and here show the converse in terms of weight of grass, which increased more or less consistently along the same gradient. An exception occurred at site 11, where the weight of grass decreased.

The relationship of categories A, S, C and V for sites 3, 4, 7, 10 and 11 was approximately the same as site [illegible] in that A, S and C were on the positive side of the second axis while [illegible] located on the negative side. The other three sites 5, 6 and [illegible] had a less consistent dispersion although in all but one, site 5, V remained on the negative side of the second axis. It appears that grass was again responsible for this arrangement. The latter three sites had the highest weights for grass, while site 5 had the highest value of all. The correlations among the categories also followed this separation of sites into two groups. In the first group, 1, 3, 4, 7, 10 and 11, A samples were invariably not correlated or poorly correlated with S and C samples, and all three of these were negatively correlated with V. The second group, 5, 6 and 9, did not demonstrate any consistency.

The null model (Table 11 & Figures 11a & 11b)

Of the hypothetical data, nearly 90% of the variation was accounted for by the first two axes (Table 11). The quality of display for most taxa and all categories was very good. The contributions of each of A, S, C and V to total inertia was fairly similar, with the extremes differing by a factor of about 2. All four categories were of equal significance, although there appeared to be no correlation among them, as can be seen in the distribution plot (Figure 11b). In terms of taxa, grass was the most significant contributor to total inertia, followed by *Rhus*, *Olea* and *Celtis*. However, the greater contribution of some taxa to total inertia is simply an artefact produced by the fact that some taxa overwhelmed others in the pollen spectrum. Figure 11a shows a random distribution of taxa. The co-ordinate scale in Figures 11a and 11b is much larger than the scale for site 1 (Figure 10), so that the display of the null data tends to be exaggerated.

Figure 12a projects the taxa of site 1 onto the hypothetical data display, while Figure 12b does the same for categories. The apparently random null data now become clustered about the origin, while the real data are widely scattered. This was reflected in the numerical data of site 1, where there was a nearly 8-fold difference in individual contribution of A, S, C and V to total inertia. Such extreme differences were also seen in data for the other sites (Appendix 7).

5.3.2 Pollen production and climatic factors

Table 12 shows that when data from all sites is combined, annual average temperatures and rainfall were consistent with long-term data for Pretoria and Johannesburg (Climate of South Africa 1986). In contrast when fine resolution is used, Table 13 shows tremendous between-site variability in rainfall. For example in March 1987, site 7 with 264.8 mm, had more than four times the rain of site 11 with 62.7 mm. Corresponding to these rainfall anomolies, Table 14 shows that grass pollen production varied considerably, even though sites were located within a small area. Not surprisingly then, for the time period quoted above (March 1987), only 0.5% of annual grass pollen was recorded at site 7, and 14.2% at site 11 (Table 14).

5.3.3 Pollen diagram (Figure 9)

The pollen diagram provides a visual comparison of the input data of the CA. The predominance of grass in all categories is highlighted. The excessive pollen counts for wind-pollinated trees and insect-pollinated non-arboreal taxa compared to vegetation cover, is confirmed.

Marshy plants were not well represented in soil samples derived from marshes.

Grass pollen at all sites for most samples was more durable than other taxa. This can be seen in Figure 9 where the percentage of grass pollen in the A sample was less than in the B sample, which was again less than that in the C sample. These percentages were 53.46%, 54.56% and 58.72%.

5.3.4 Pollen and land-use

Although vegetation quadrats were chosen to exclude alien taxa, these were well represented in the atmospheric pollen spectrum (Table 15). Even site 11, located in a nature reserve at some distance from any alien trees, showed a considerable presence of alien atmospheric pollen (18.72%).

5.4 Discussion

5.4.1 Pollen and vegetation

The most salient feature of this analysis was the marked over-representation of anemophilous trees relative to grass. Entomophilous non-arboreal taxa were also over-represented, so that even small specimens in the local vegetation, both in terms of size of the individual plant and percentage contribution, were exaggerated. In contrast, both grass and insect-pollinated trees accurately reflected vegetation. The net result was that pollen samples were not indicative of the surrounding vegetation.

This result was highlighted by the comparison of the real data with the null model, which tested the assumption that pollen is indicative of vegetation. If the display of the null model is examined in isolation, it appears that there is a random distribution of taxa about the origin, without any clustering. The outliers that emerged in the analysis of real data for the sites are still apparent, but none has any significance. The numerical output shows that grass is the only taxon that carries any weight, with a smaller contribution from *Rhus*. In terms of categories, all four are equivalent, so that if the null data had been true there would have been no variability among the different types of samples. However, as soon as the real data for site 1 are superimposed on the null model, the null model becomes questionable. The apparent randomness of the null data is contracted into a very small area of the display, while the real data points are widely scattered. This implies that real data are much more variable than the hypothetical data of the null model suggests. If the data of the null model had in fact been that of a fossilised situation, the assumption of equivalence of samples would have been erroneous.

The second feature of importance that emerged was the difference between the pollen content of atmospheric, surface and core samples.

Grass was unique in that it was the only wind-pollinated taxon that accurately reflected the vegetation. Correlation with A, S and C categories was negative, but in this case the explanation lay not with grass itself. Grass *per se* would probably have correlated very highly with all categories if examined in isolation;

However, in an assemblage such as this which included all aspects of the vegetation, grass was examined alongside anemophilous tree taxa. These appeared to distort the analysis due to production of disproportionately large numbers of pollen. To have excluded either one or the other from the analysis would have been illogical, so that these caveats must be borne in mind when considering the plots.

This distortion was highlighted at site 11, where the weight of grass in the CA showed an unexpected decrease. This site was located entirely within the Bankenveld, but near a woody ridge. Grass constituted the major part of the vegetation, but the pollen was masked by anemophilous trees.

Of the arboreal taxa the most predominant in terms of pollen were the anemophilous taxa *Rhus* and *Celtis*. They were negatively correlated with vegetation, on account of the excessive pollen production, and positively with the other three categories.

In contrast, there was a large number of trees highly positively correlated with vegetation. However, they appeared insignificant due to their low weights, as seen in the numerical analysis of the CA. These low weights were the result of low pollen counts for these trees, all of which were insect-pollinated. The fact that they were positively correlated with vegetation and negatively correlated with the other categories, could also be explained by their entomophilous nature. This meant that relative to anemophilous trees they were under-represented in a pollen sample, but equally represented in an analysis of vegetation.

Outliers that appeared highly correlated with one or the other category were invariably of low weight. Their apparently anomolous positions were due to their localised presence at sites, but they did not exhibit any definite trends. They were frequently taxa that had a spotty occurrence, appearing in only one or two of the pollen categories or being present in vegetation but not in pollen samples.

The quality of the soil samples examined may have significantly affected this analysis. I found that the number of grains per unit volume differed from site to site. Some samples were rich in pollen, while others required laborious counting to reach 250, even in some of the wetter, marshy areas. This poor pollen preservation was probably linked to the rainfall regime, and possibly to the so-called wet-and-dry cycles (Tyson 1986). These cycles of approximately decadal duration mean that the height of the water table is not maintained, so that even marshy areas become dehydrated during dry periods, resulting in oxidation of pollen. This was confirmed by the paucity of marshy plant pollen in soil samples derived from marshes. It is feasible that a shifting water table would not be conducive to pollen preservation, especially if grains were selectively susceptible to oxidation. The greater preservation of grass pollen in atmospheric samples, compared to the other categories of sample, further supports this suggestion.

Inter-site differences were very noticeable in this study, even though sites were located within a small area. An explanation which appears to suffice is that of unreliability of rainfall, superimposed on the cyclical decadal pattern. Unreliability of rainfall can be seen in the many instances of anomolous rainfall measurements. For example at site 11 September rain during 1987 was 1246% that of normal. A two-year data base is not able to establish 'normal' pollen production at a particular site, so that this study cannot compare pollen production to abnormal rainfall. It would also be necessary to establish absolute pollen production, which was not attempted in this part of the analysis. However, such abnormally heavy spring rains at the start of the growth season can be expected to contribute substantially to between-site as well as between-year differences in pollen production. This was confirmed in Chapter 4 where cross-correlation analysis indicated a positive two-to three-month lag relationship between rain and grass pollen derived from the Burkard samplers.

The area of the vegetation quadrats may have been a limiting factor, and a change in size may have altered results. However, such a change may have affected wind-pollinated trees only, if any. Turner (1964) found that Pine pollen showed high values of deposition only near the source, exponentially decreasing to low values over 400 m. Anderson (1970) showed that pollen deposited on a forest floor was largely derived from trees within 20-30 m of the sampling site. These two studies indicated conditions for anemophilous trees. A South African study on the grassland species *Themeda triandra* by Robinson and Lowrey (1988) concluded that the majority of pollen grains travelled a very short distance from the plant, with an average of 0.684 m. These three studies indicate that in the PWV each quadrat was adequately sampling the grass component, and probably the wind-pollinated trees as well. Further, it appears that there was no background pollen (Birks & Gordon 1985) for grass, and probably very little for trees.

5.4.2 Pollen and land-use

The abundant presence of alien pollen taxa in the atmospheric pollen spectrum (Table 15) indicated the extent to which alien taxa have replaced native vegetation, and the success of temperate tree taxa in terms of anemophily. This was especially clear at site 11 which was located in a nature reserve, at some distance from any alien trees.

The PWV was colonised by white settlers about one hundred years ago, at which time alien taxa were introduced. However, pollen of such taxa was almost entirely absent from both categories of soil samples, so that no conclusions could be made about changes over time in land-use. This poor preservation again highlights the possible detrimental effect of the rainfall regime.

Indigenous people who inhabited the area prior to settlement cultivated cereals on a limited scale. If such early varieties were characterised by pollen grains larger than those of the native grasses, this was not apparent in the samples.

5.5 Summary and conclusions

1. Of the anemophilous native taxa occurring in the PWV, grass was most closely correlated with the vegetation. Entomophilous tree taxa were also well correlated with the vegetation, even though their low numbers made them appear less significant. It is possible that this was an artefact of the CA, and that together with grasses, they were in fact very sensitive indicators of the vegetation.

2. Anemophilous tree taxa were seriously over-represented, due to the large numbers of pollen that were produced by these taxa, relative to the number of trees.

3. Entomophilous non-arboreal taxa were also over-represented, since the amount of pollen produced was disproportionate to the small size of these taxa.

4. These mis-representations indicated that pollen was not an accurate reflection of the vegetation in the predominant grasslands of the study area, if the pollen spectrum was considered in its entirety.

5. In addition, surface and subsurface pollen samples did not match atmospheric samples. This was coupled to inter-site differences in pollen production. It is suggested that

unreliability of rainfall and possibly a link to the so-called wet-and-dry decadal cycles were the major cause of these discrepancies.

6. There was a large presence of alien pollen in all atmospheric samples, indicating current altered land-use practices. Such pollen was almost totally absent from the soil samples, so that it was not possible to extrapolate past changes in land-use.

Chapter 6

Summary and Conclusions

A two-year analysis of the airspora, composed of pollen and fungal spores, was conducted in the Pretoria-Johannesburg-Vereeniging district of the Transvaal, South Africa. The study investigated various aspects of the relationship between pollen and vegetation. Meteorological and longer-term climatic factors, and their influence on the airspora, were examined. Atmospheric and soil-derived pollen was compared to establish the reliability of palaeoenvironmental conclusions. Pollen, as an indicator of land-use patterns, was examined. The potential allergenicity of the airspora was investigated.

The vegetation of the study area is predominantly grassland of the Bankenveld, merging with the Sourish Mixed Bushveld of the Tropical Bush and Savanna Type in the northern limits of the study area (Acocks 1975). Eleven sampling stations were located within this area.

Airspora data were collected by two methods. The first method was gravitational, with samplers located at each of the eleven sampling sites. The second method employed two Burkard Seven Day Recording

Volumetric Spore Traps, sited at two of the sites. Soil was sampled at each site. Meteorological data were obtained from the South African Weather Bureau.

Pollen calendars were constructed for Johannesburg and Pretoria. Various correlation analyses were conducted, comparing meteorological data to the airspora. Correspondence analysis made both inter- and intra-site comparisons.

The answers to the questions posed at the outset of this study are summarised below, in the light of findings to date.

1. What are the qualitative and quantitative relationships between atmospheric pollen and local and regional vegetation?

The predominant regional grassland vegetation was strongly reflected in the high percentage of grass pollen in the atmosphere. This taxon comprised 52% of the regional pollen total.

Native trees were poorly represented in the pollen spectrum. This was partly due to the lack of trees in the natural vegetation and partly due to the greater entomophily among native tree taxa. However, the few anemophilous tree taxa that did occur showed regional quantitative differences in pollen. This reflected differences between the vegetation and climate of Johannesburg and Pretoria.

The quantitative relationships between pollen and vegetation were superimposed on the above qualitative relationships. Only grass pollen and insect-pollinated tree pollen were found to be correlated with vegetation. Wind-pollinated trees were seriously over-represented in atmospheric samples due to the large numbers of pollen produced by these taxa, relative to the number of trees. Insect-pollinated non-arboreal taxa were also over-represented, as the amount of pollen produced was not equivalent to the small size of these taxa.

2. What are the qualitative and quantitative relationships among the atmospheric, surface and subsurface (subfossil) pollen samples, and how do these relate to the local and regional vegetation?

Atmospheric, surface and subsurface samples did not reflect the same composition across the pollen spectrum, with little correlation among these samples at most sites. Considerable inter-site variability was also recorded. The cause of this variability between both samples and sites was probably the unreliability of the rainfall. This was seen in both inter-site differences and in the inter-annual rainfall anomolies. The so-called wet-and-dry decadal rainfall cycles may also have played a role in the variability among samples.

As explained above, the net result of the misrepresentation of atmospheric pollen meant that there was a poor relationship between such pollen and vegetation, if the entire pollen spectrum was considered. If only certain selected categories were considered, the relationship became more m. ningful. The lack of correspondence between atmospheric and soil samples meant that any postulated relationship between the latter and vegetation was even more tenuous.

3. How can the atmospheric, surface and subsurface samples be used to reconstruct palaeoclimates?

Given the above limitations, an analysis of a fossilised pollen sequence in this region would be exceedingly complicated. The atmospheric pollen did not accurately reflect the vegetation, and the soil samples were not consistent with the atmospheric samples. If the current anomolies had been consistent over time, a fossilised assemblage would not accurately reflect the atmospheric component. In addition an interpretation of the vegetation would be difficult. Entomophilous taxa would have to be treated cautiously as they would reflect only extremely localised vegetation. Anemophilous trees would be seriously over-represented. The most favourable interpretation would possibly be made by considering only grass and entomophilous trees, and by treating other taxa circumspectly.

4. What role do metorological factors play in concentration and distribution of pollen rain, and what effect does this have on the interpretation of pollen rain?

Temperature was the most important meteorological factor controlling both concentration and distribution of grass pollen, with a positive relationship. A positive relationship was also seen between spring rain and summer grass pollen.

Considerable variation was seen between grass pollen in Johannesburg and Pretoria. As meteorological factors between the two cities correlated highly, it was suggested that the native grasses of the two different vegetation regions were responding differently to the different long-term climatic conditions of these cities.

In examining the relationship between fungal spores and meteorological factors it was found that fungal spores responded more finely than pollen to conditions in the immediate vicinity of the sampling stations.

5. What is the relationship between l[illegible] rain?

The relationship between pollen rain and land-use in the PWV area was illustrated by the high percentage of alien taxa in the atmospheric pollen samples. In the city, alien pollen accounted for 51% of total pollen. This percentage decreased away from the city, but even in rural areas alien pollen accounted for almost 19% of total pollen. This indicated the extent to which native vegetation has been replaced by alien vegetation. However, the above observations on the over-representation of native anemophilous tree taxa caution against over-zealous interpretation of the high number of alien pollen, since the majority of these taxa were also anemophilous.

Finally, the allergenicity of the airspora was considered. It was concluded that there were several problem areas. First, highly allergenic grass pollen was the largest component of the pollen spectrum, comprising 52% of the regional total. The second problem was the high pollen count in the spring, attributable to the allergenic northern hemisphere taxa. Third, 58.8% of the total pollen count was non-seasonal, and present throughout the year. Lastly, fungal spores comprised 94% of total airspora. The majority of these were also highly allergenic, and recorded throughout the year with peaks in late summer and autumn.

Chapter 7

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Chapter 8

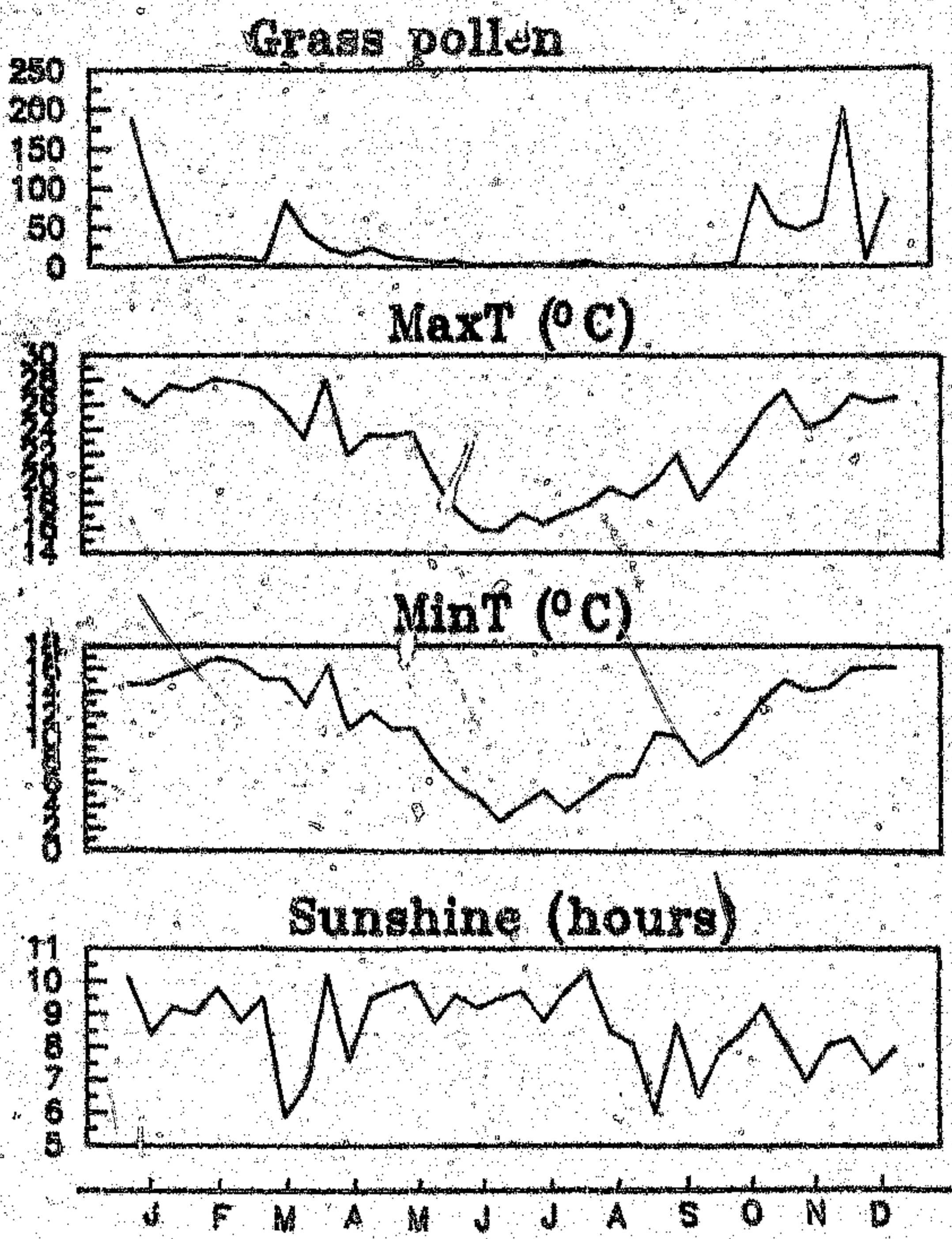
Appendices

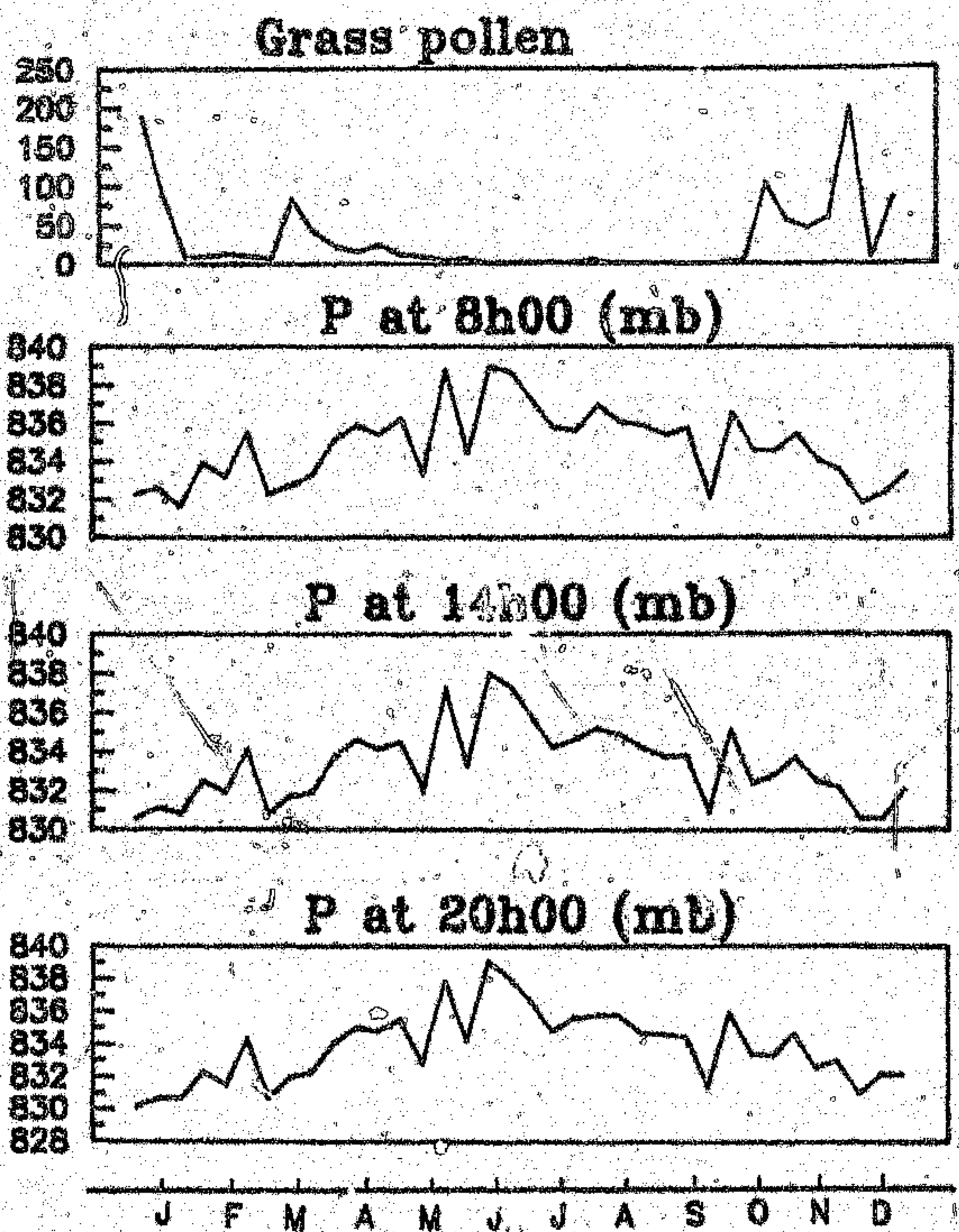
Appendix I Annual distribution plots of airspora and meteorological factors

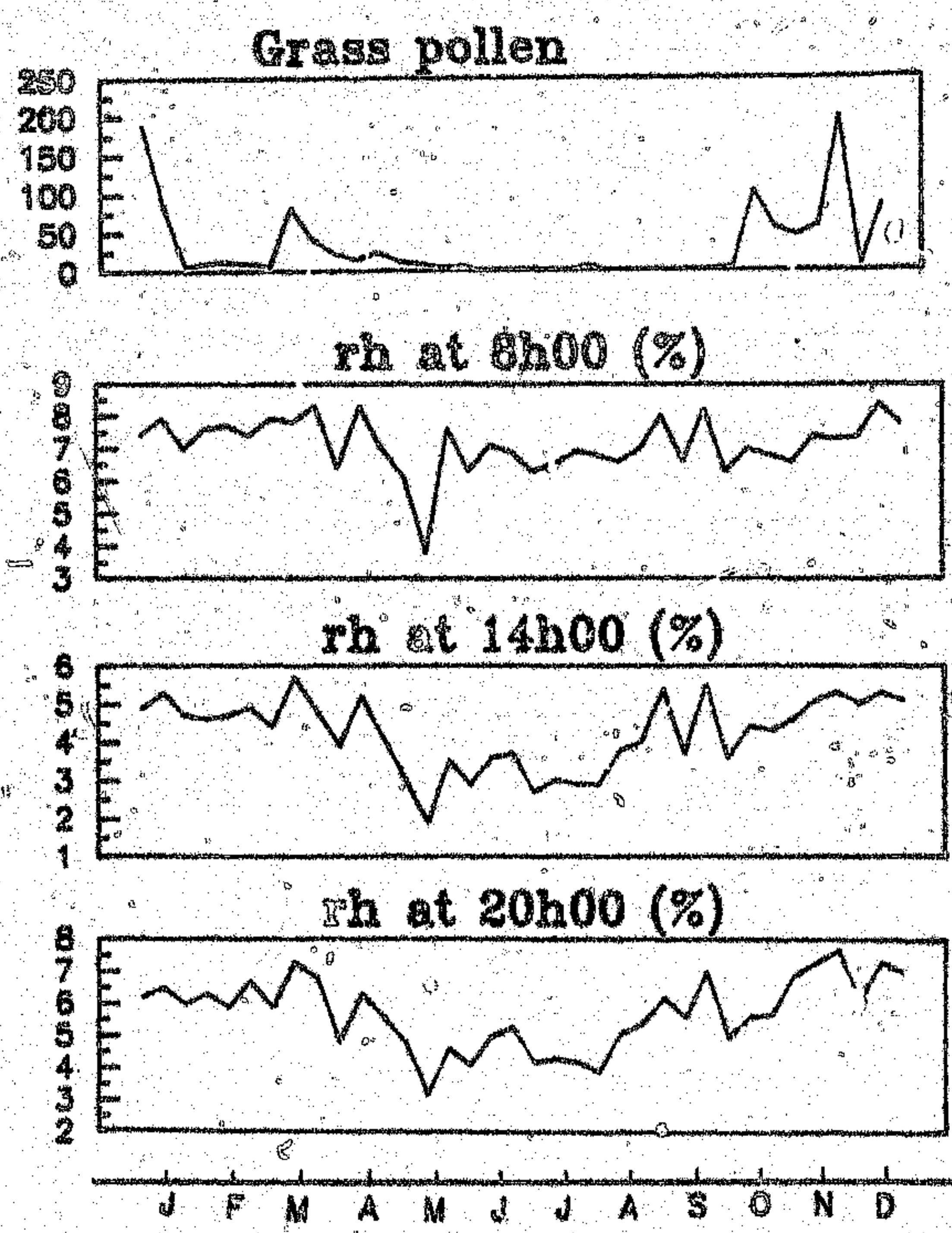
(Airspora measured in number m^{-3} of air day^{-1}

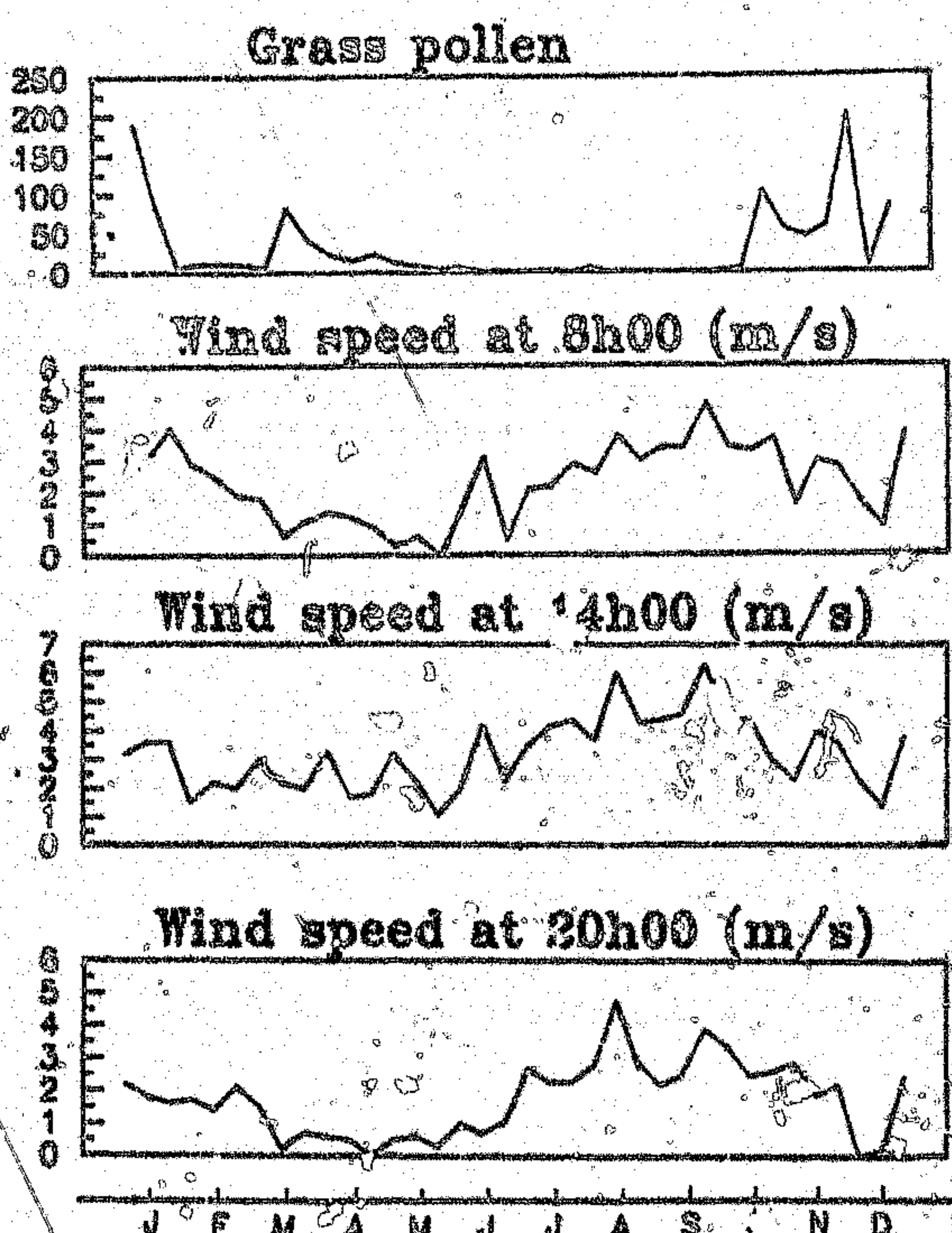
where Max T = maximum temperature
Min T = minimum temperature
P at 8h00 = pressure at 8h00
P at 14h00 = pressure at 14h00
P at 20h00 = pressure at 20h00
rh at 8h00 = relative humidity at 8h00
rh at 14h00 = relative humidity at 14h00
rh at 20h00 = relative humidity at 20h00).

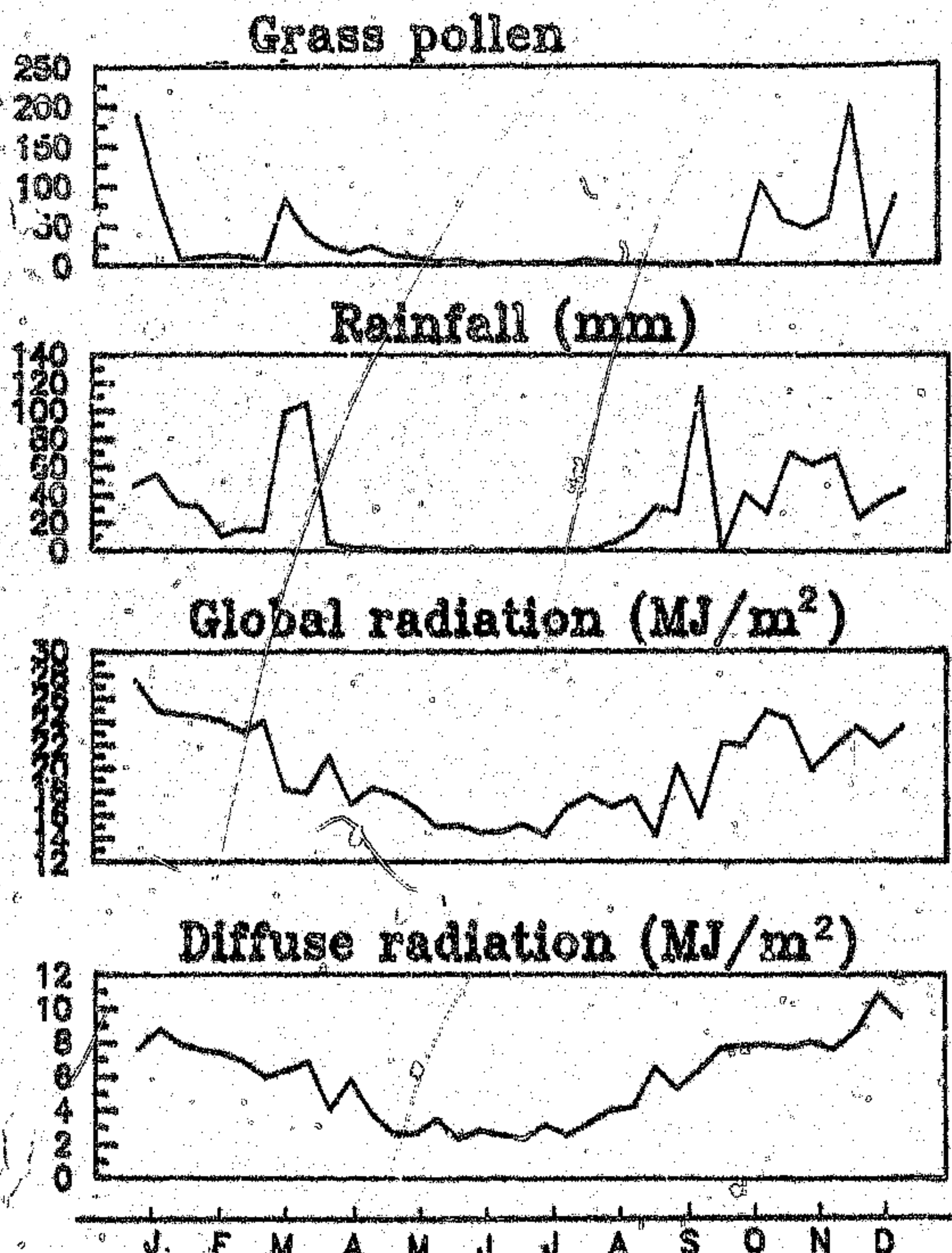
Appendix 1a Grass pollen and meteorological parameters in Johannesburg, 1987.



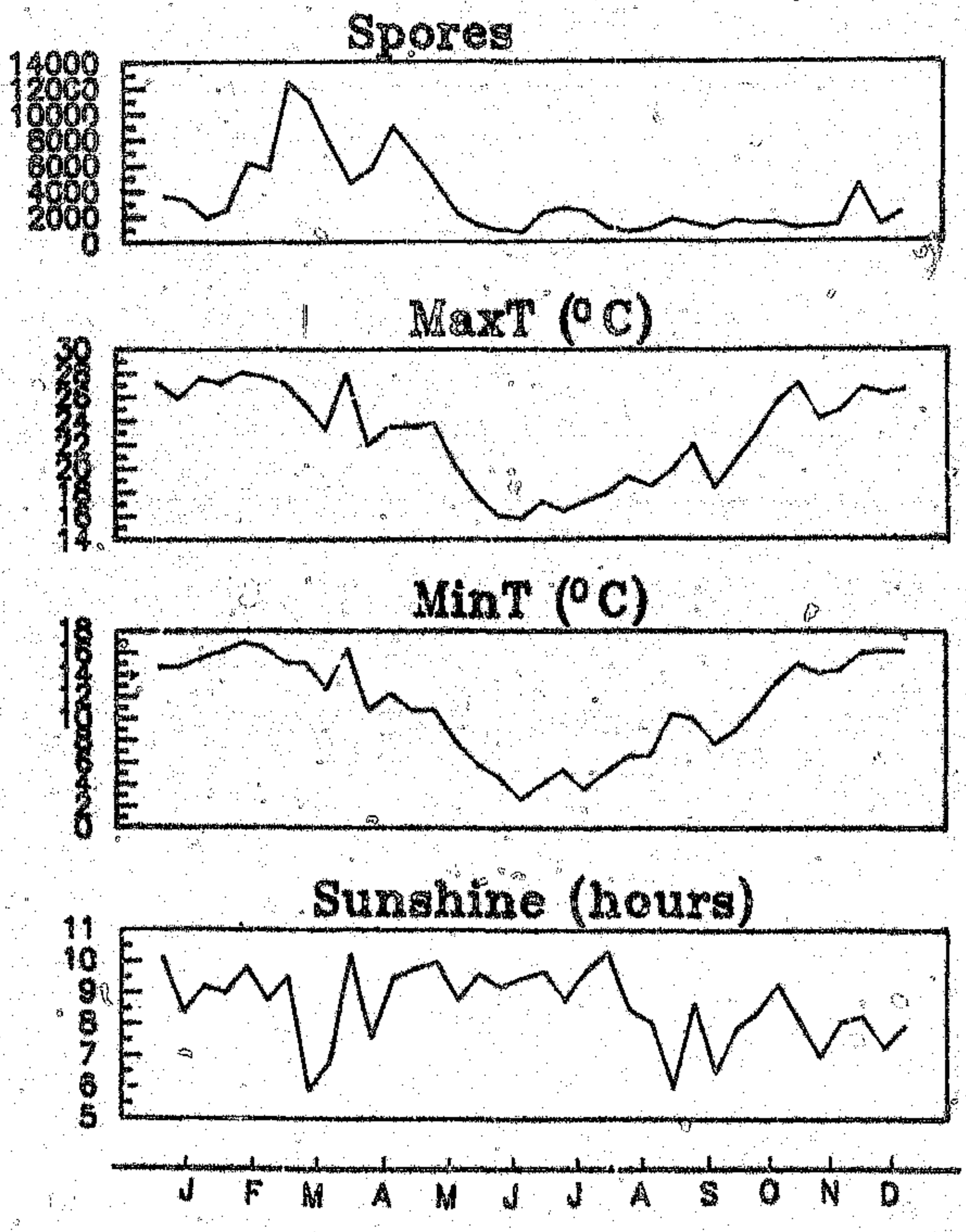

Grass pollen
250
200
150
100
50
0
P at 8h00 (mb)
840
838
836
834
832
830
P at 14h00 (mb)
840
838
836
834
832
830
P at 20h00 (mb)
840
838
836
834
832
830
828
J F M A M J J A S O N D

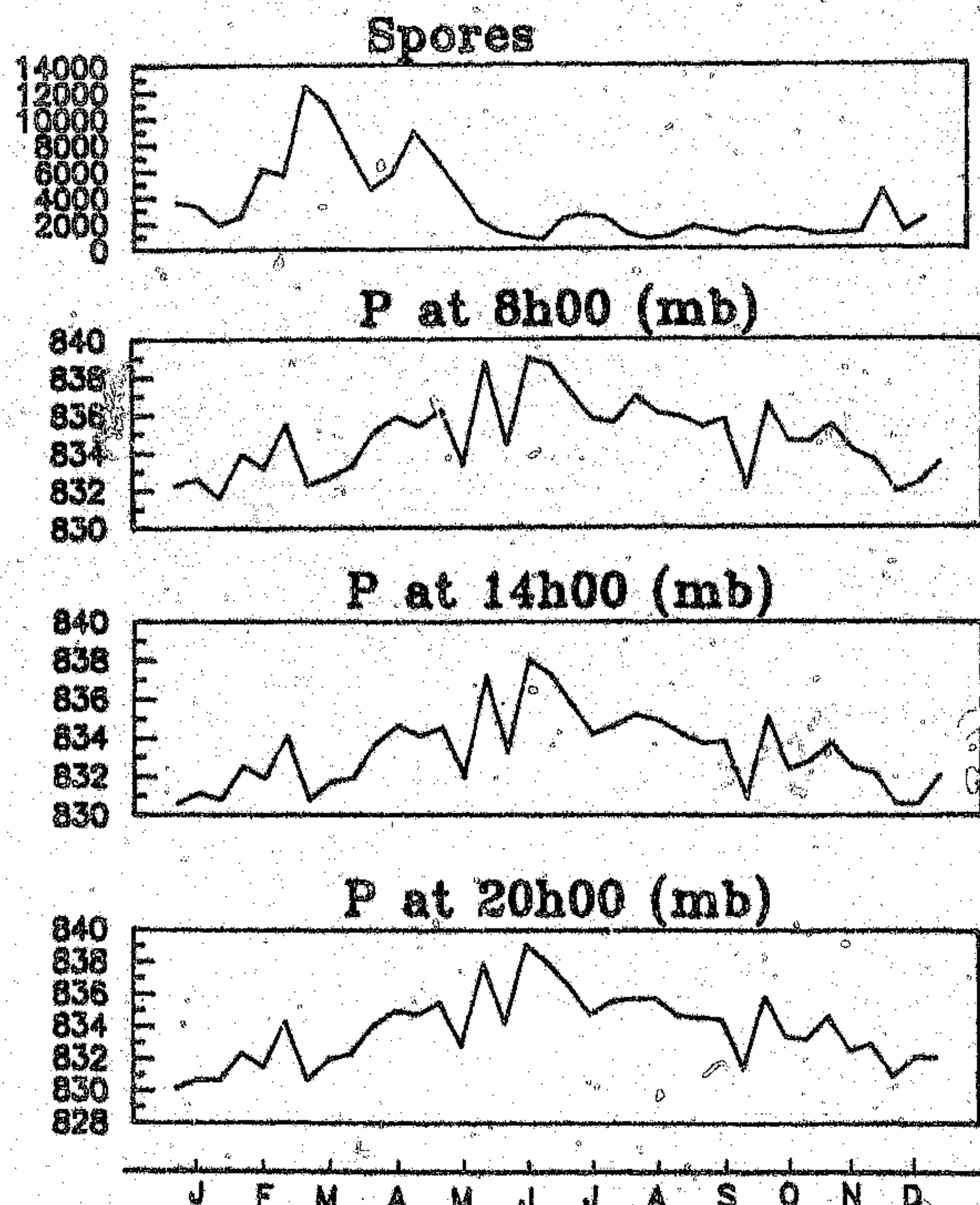

Grass pollen
250
200
150
100
50
0
rh at 8h00 (%)
9
8
7
6
5
4
3
rh at 14h00 (%)
6
5
4
3
2
1
rh at 20h00 (%)
8
7
6
5
4
3
2
J
F
M
A
M
J
J
A
S
O
N
D

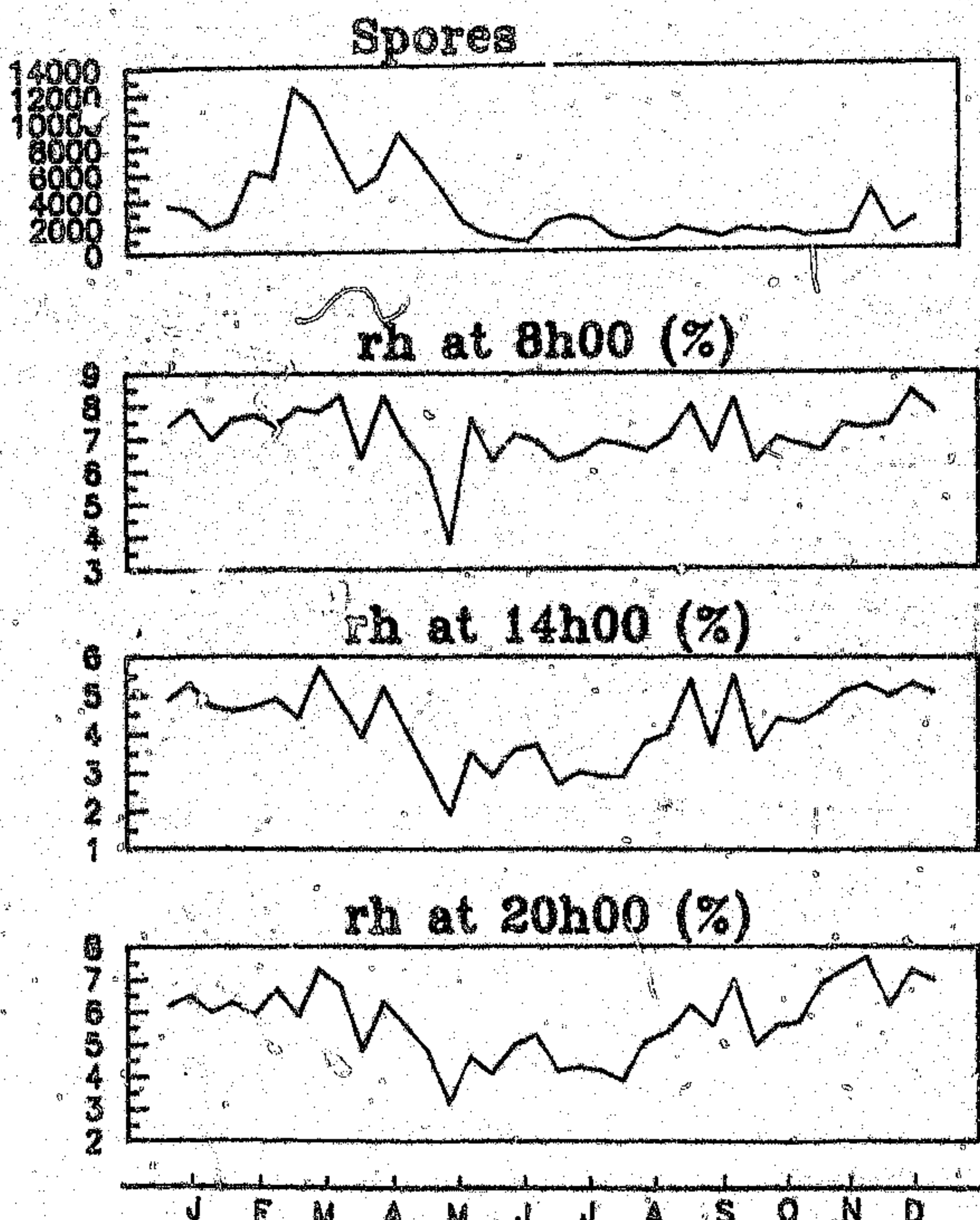

Grass pollen
250
200
150
100
50
0
Wind speed at 8h00 (m/s)
6
5
4
3
2
1
0
Wind speed at 14h00 (m/s)
7
6
5
4
3
2
1
0
Wind speed at 20h00 (m/s)
6
5
4
3
2
1
0
J F M A M J J A S N D

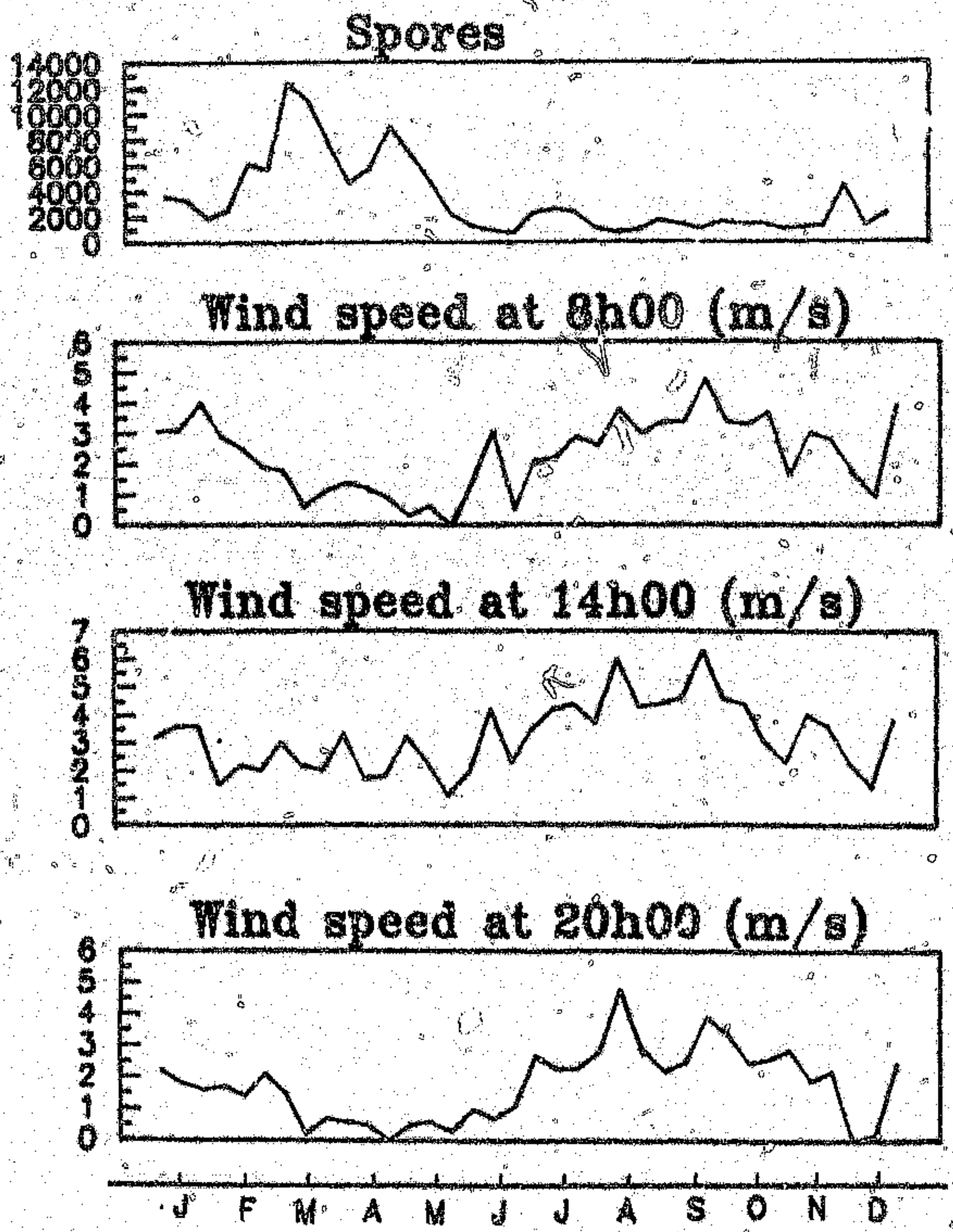

Grass pollen
250
200
150
100
50
0
Rainfall (mm)
140
120
100
80
60
40
20
0
Global radiation (MJ/m^2)
Diffuse radiation (MJ/m^2)
12
10
8
6
4
2
0
J.
F
M
A
M
J
J
A
S
O
N
D

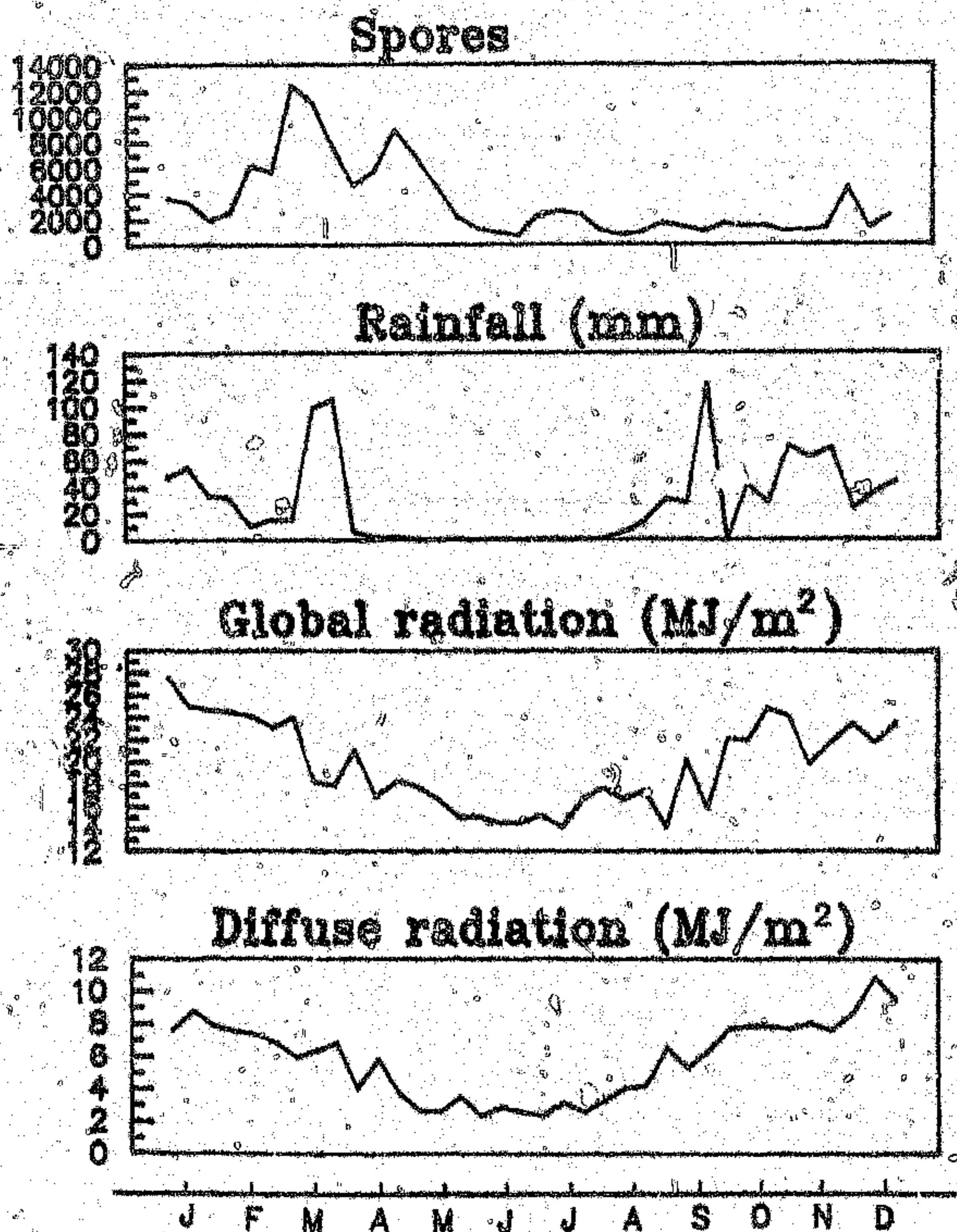
Appendix 1b Spores and meteorological parameters in Johannesburg, 1987.



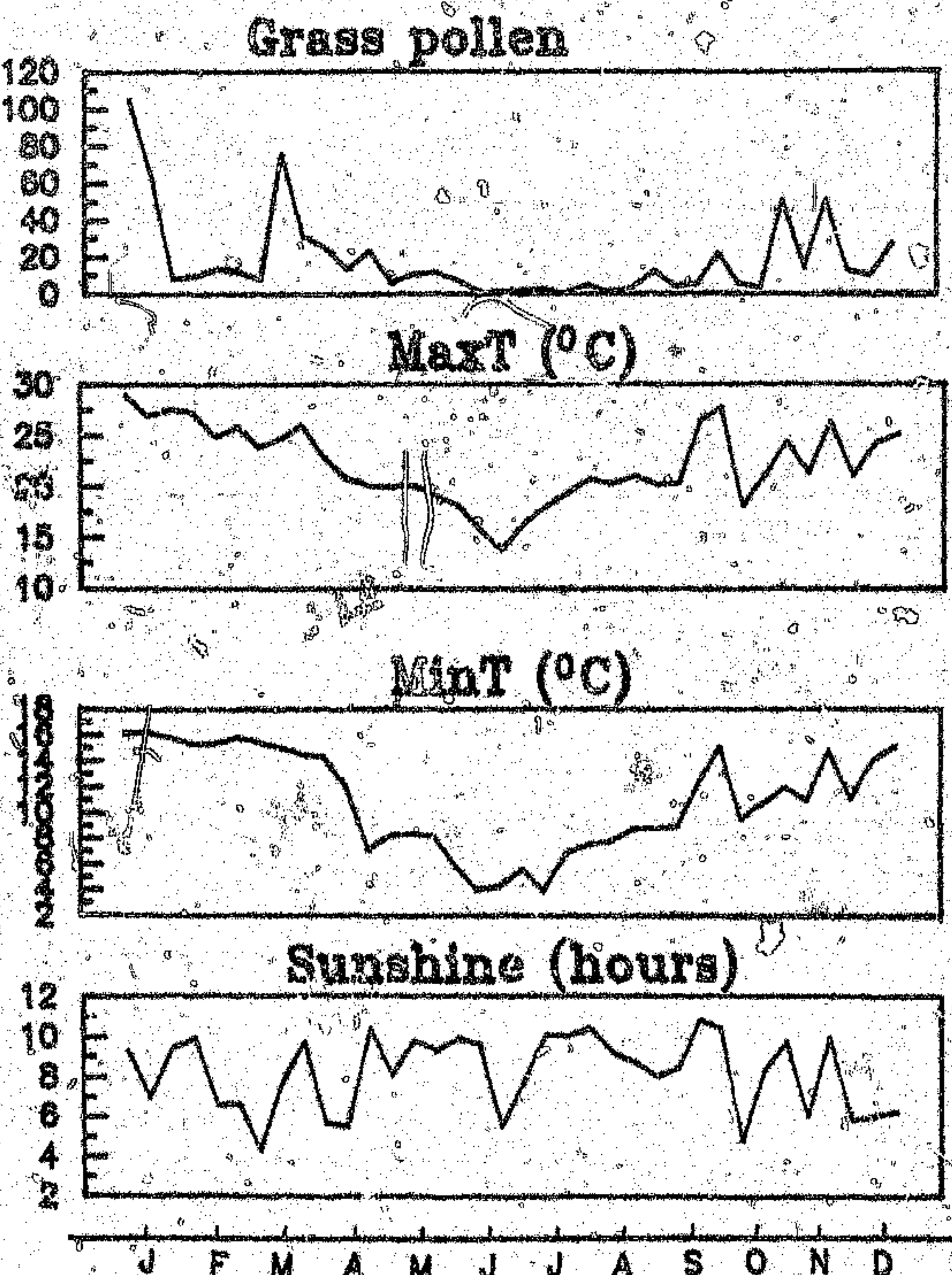

Spores
14000
12000
10000
8000
6000
4000
2000
0
P at 8h00 (mb)
840
838
836
834
832
830
P at 14h00 (mb)
840
838
836
834
832
830
P at 20h00 (mb)
840
838
836
834
832
830
828
J
F
M
A
M
J
J
A
S
O
N
D

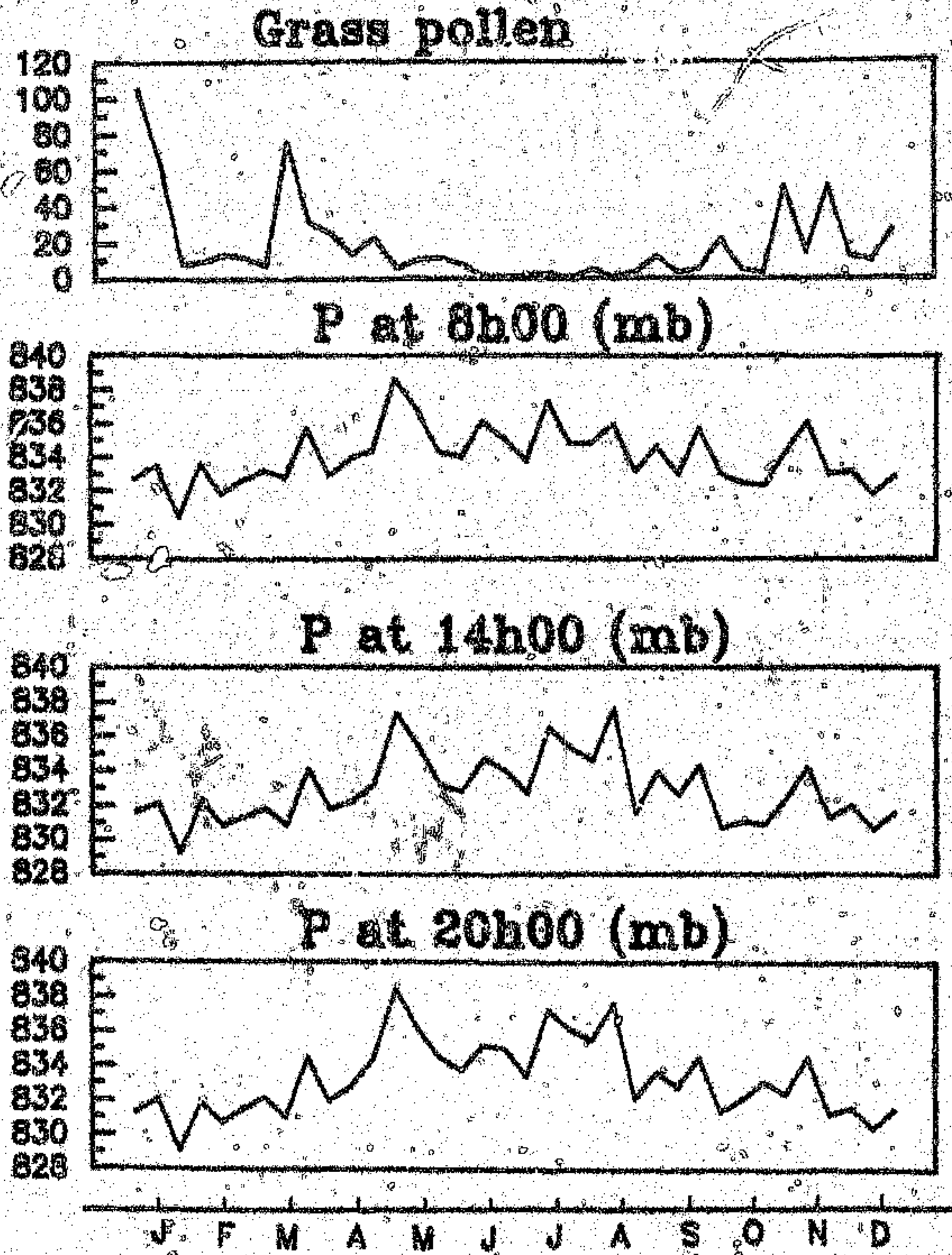

Spores
14000
12000
10000
8000
6000
4000
2000
0
rh at 8h00 (%)
9
8
7
6
5
4
3
rh at 14h00 (%)
6
5
4
3
2
1
rh at 20h00 (%)
8
7
6
5
4
3
2
J F M A M J J A S O N D


Spores
14000
12000
10000
8000
6000
4000
2000
0
Wind speed at 8h00 (m/s)
6
5
4
3
2
1
0
Wind speed at 14h00 (m/s)
7
6
5
4
3
2
1
0
Wind speed at 20h00 (m/s)
6
5
4
3
2
1
0
J F M A M J J A S O N D

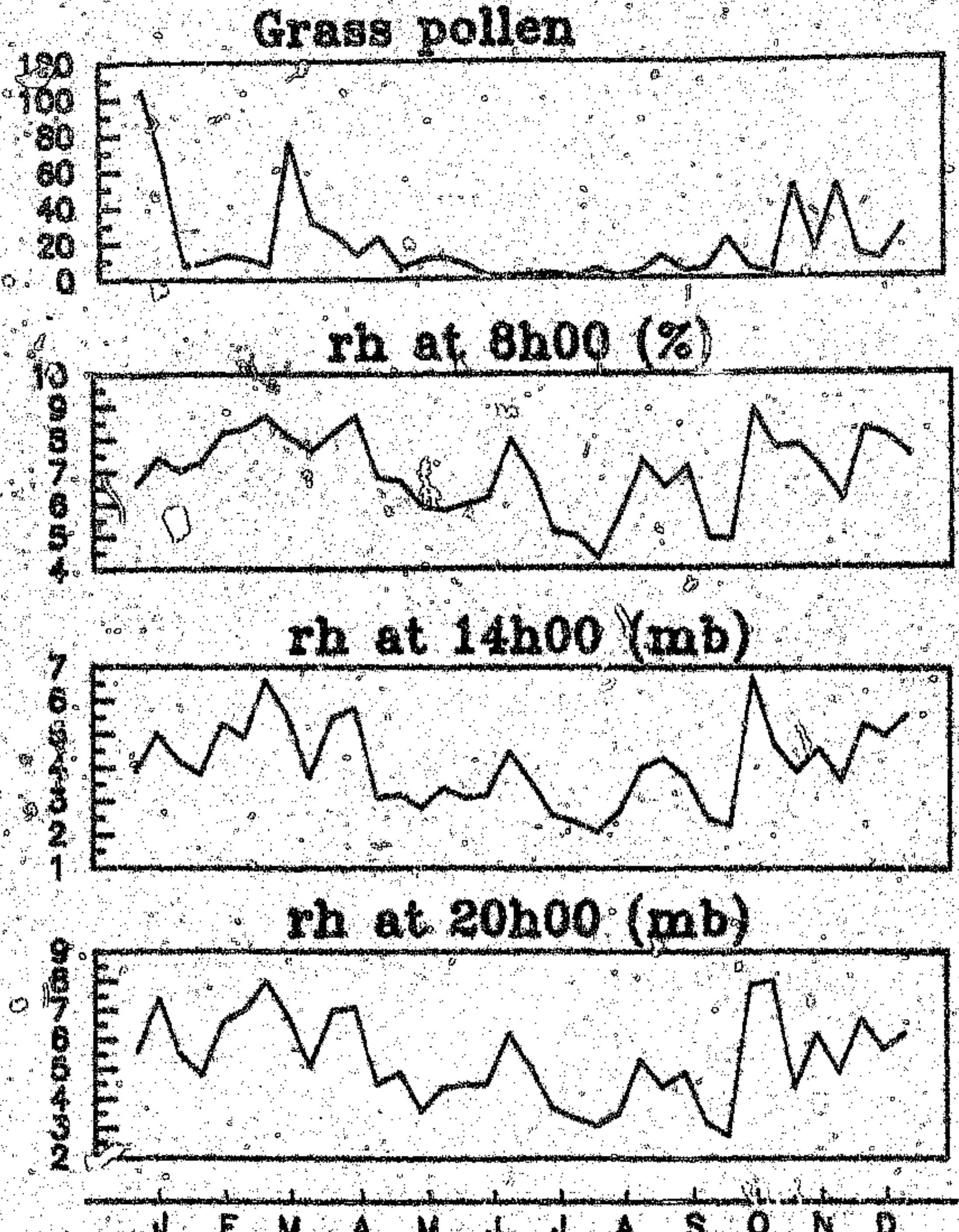

Spores
14000
12000
10000
8000
6000
4000
2000
0
Rainfall (mm)
140
120
100
80
60
40
20
0
Global radiation (MJ/m²)
30
12
Diffuse radiation (MJ/m²)
12
10
8
6
4
2
0
J F M A M J J A S O N D

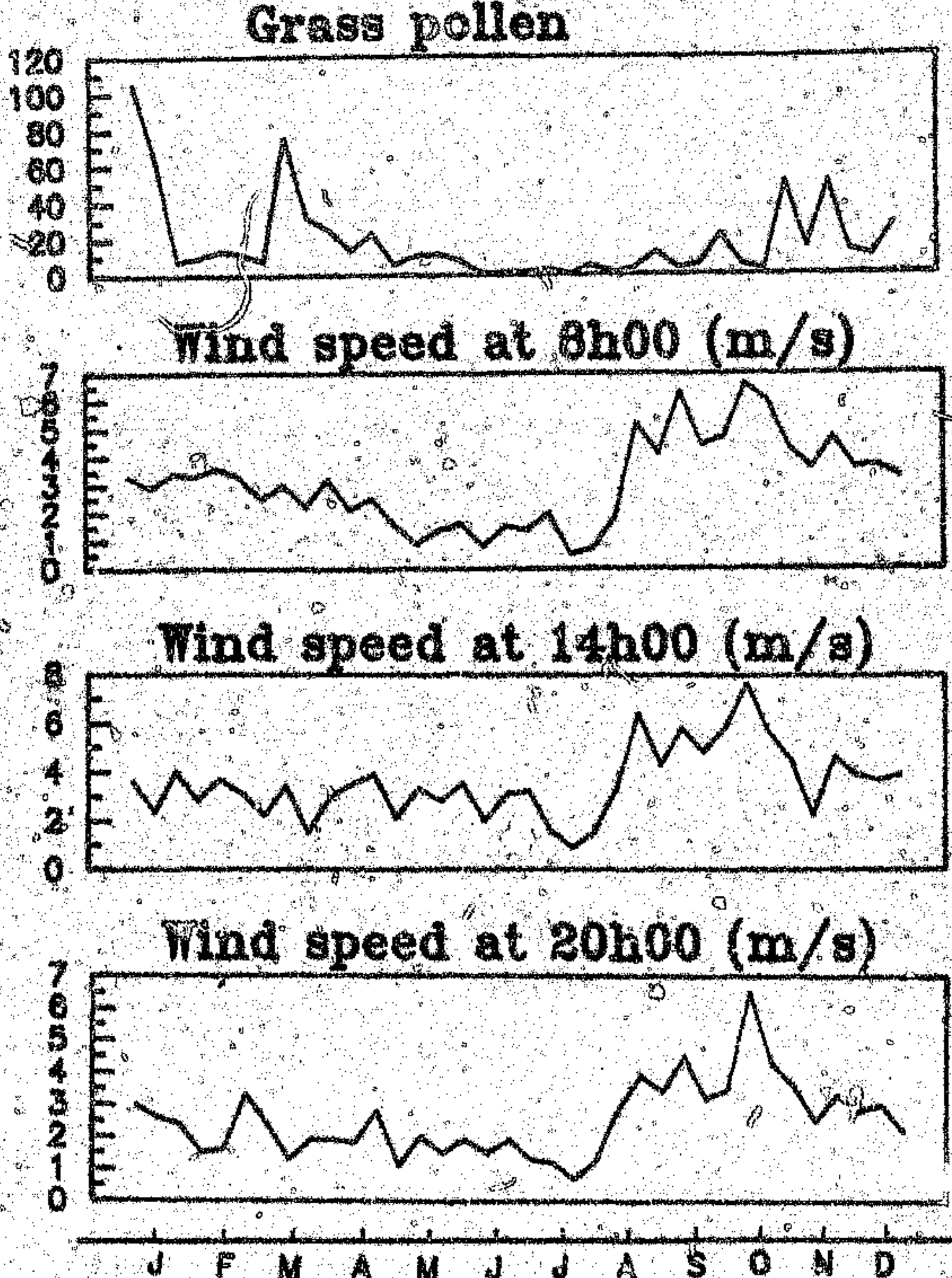
Appendix 1c Grass pollen and meteorological parameters in Johannesburg, 1988.

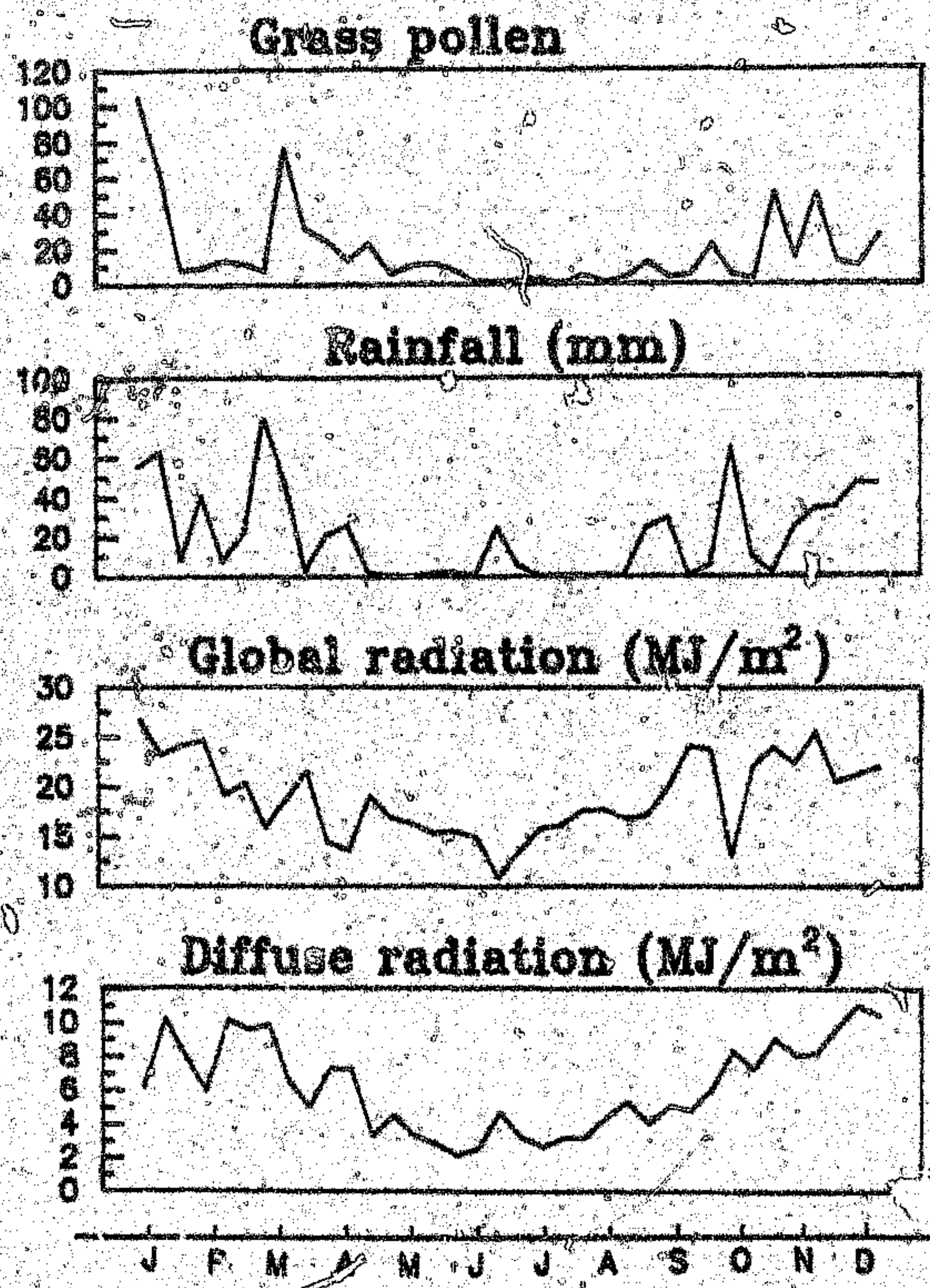




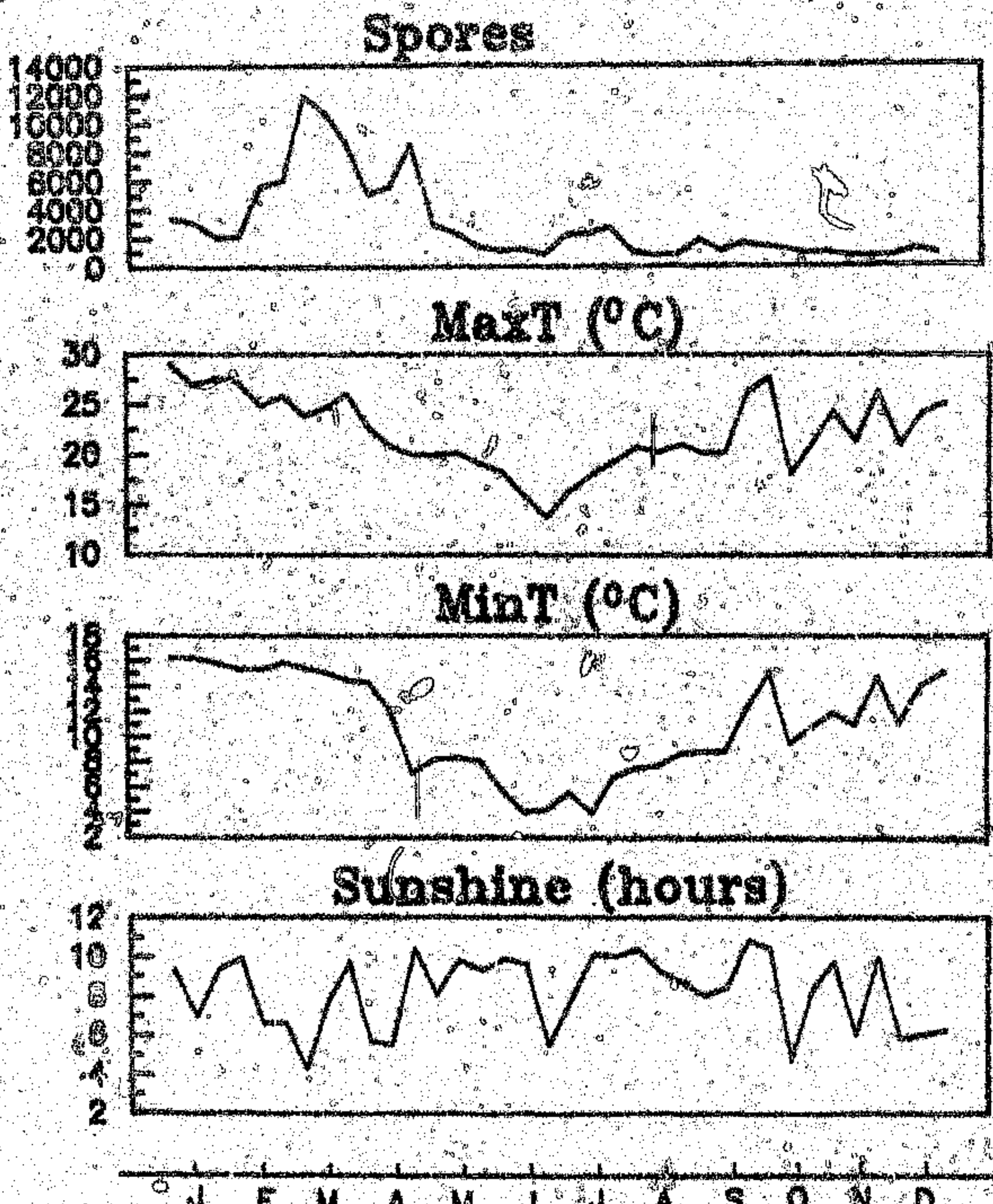
Grass pollen
120
100
80
60
40
20
0
P at 8h00 (mb)
840
838
836
834
832
830
828
P at 14h00 (mb)
840
838
836
834
832
830
828
P at 20h00 (mb)
840
838
836
834
832
830
828
J F M A M J J A S O N D

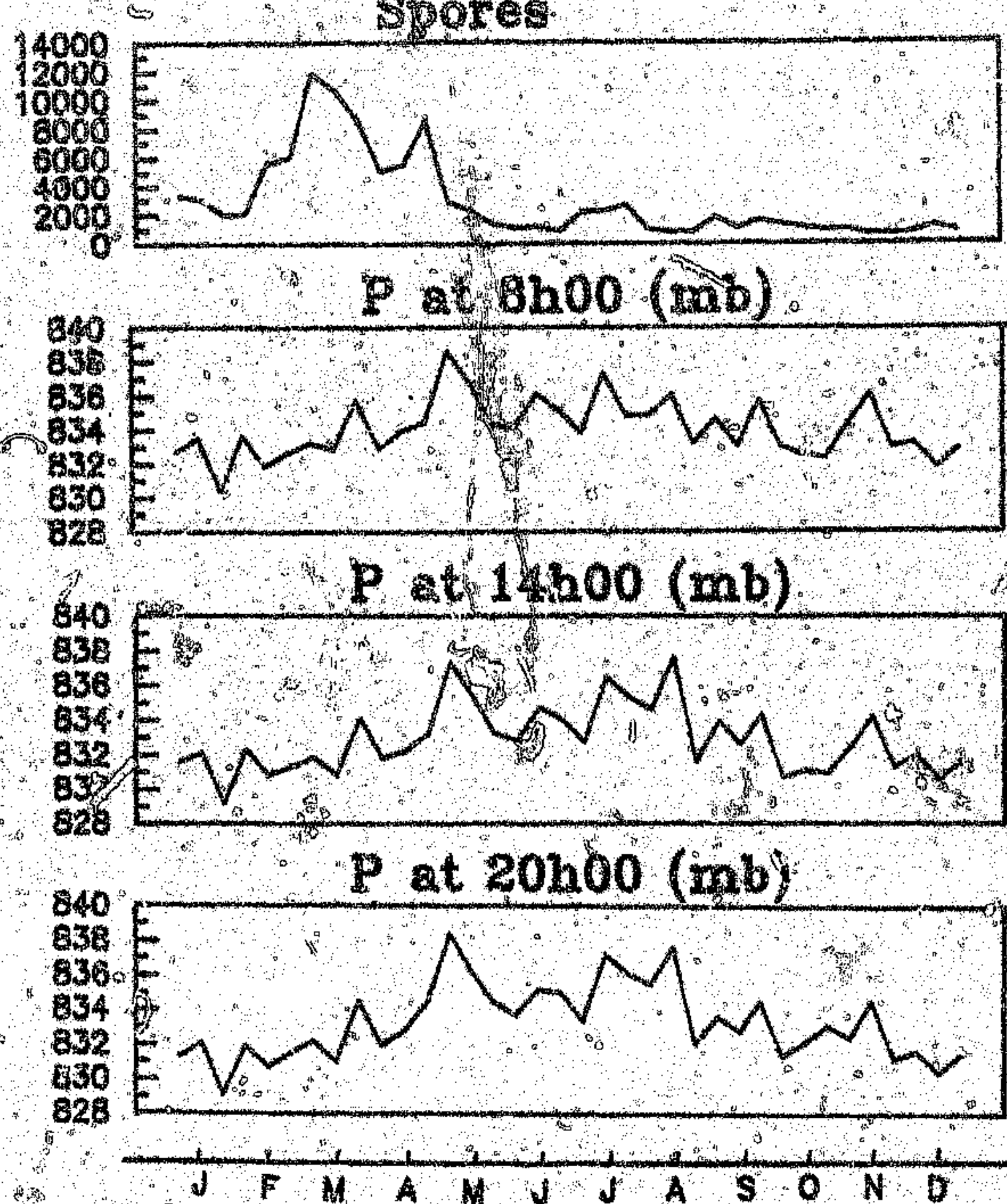

Grass pollen
120
100
80
60
40
20
0
rh at 8h00 (%)
10
9
8
7
6
5
4
rh at 14h00 (mb)
7
6
5
4
3
2
1
rh at 20h00 (mb)
9
8
7
6
5
4
3
2
J F M A M J J A S O N D

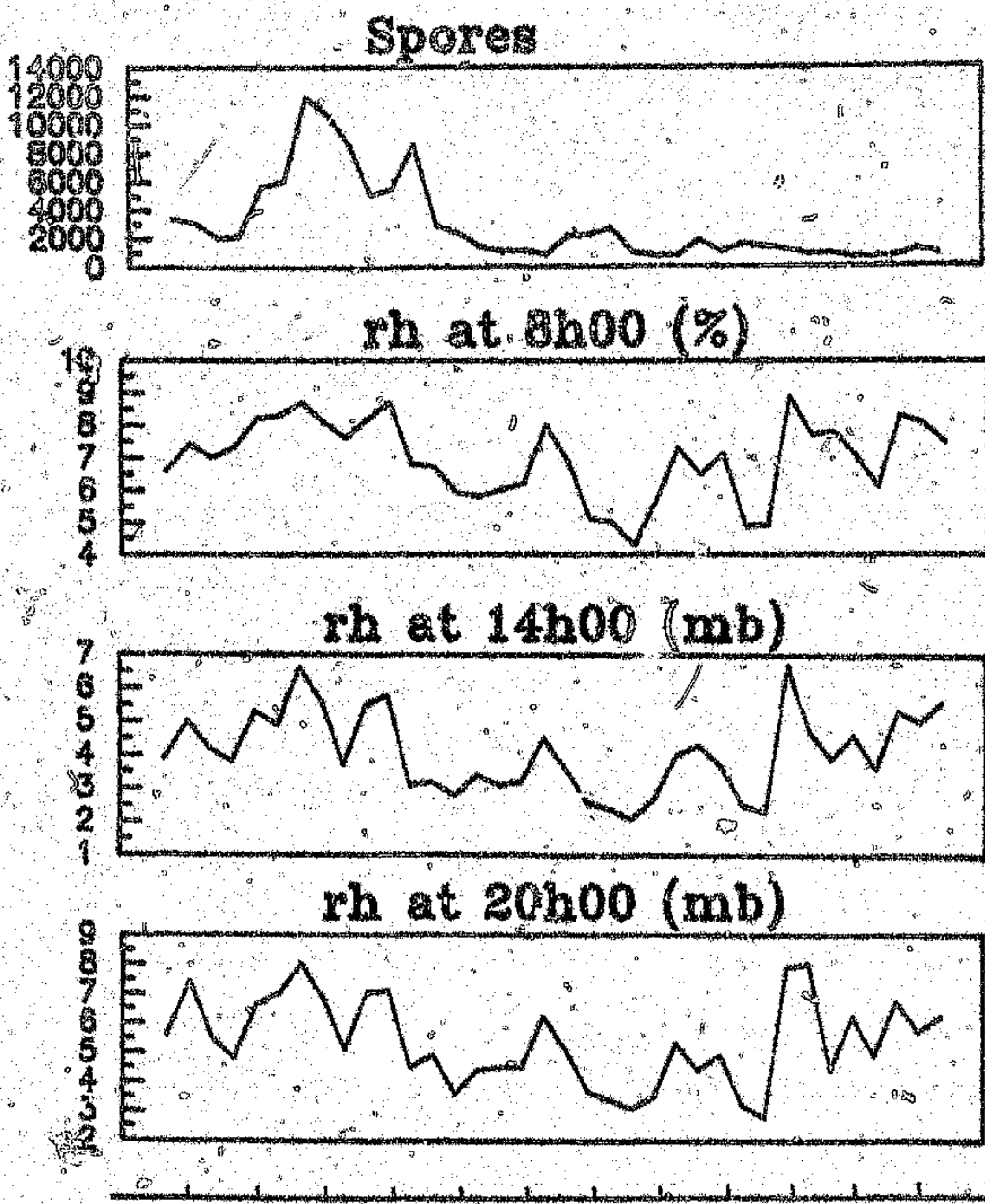

Grass pollen
120
100
80
60
40
20
0
Wind speed at 8h00 (m/s)
7
6
5
4
3
2
1
0
Wind speed at 14h00 (m/s)
8
6
4
2
0
Wind speed at 20h00 (m/s)
7
6
5
4
3
2
1
0
J F M A M J J A S O N D

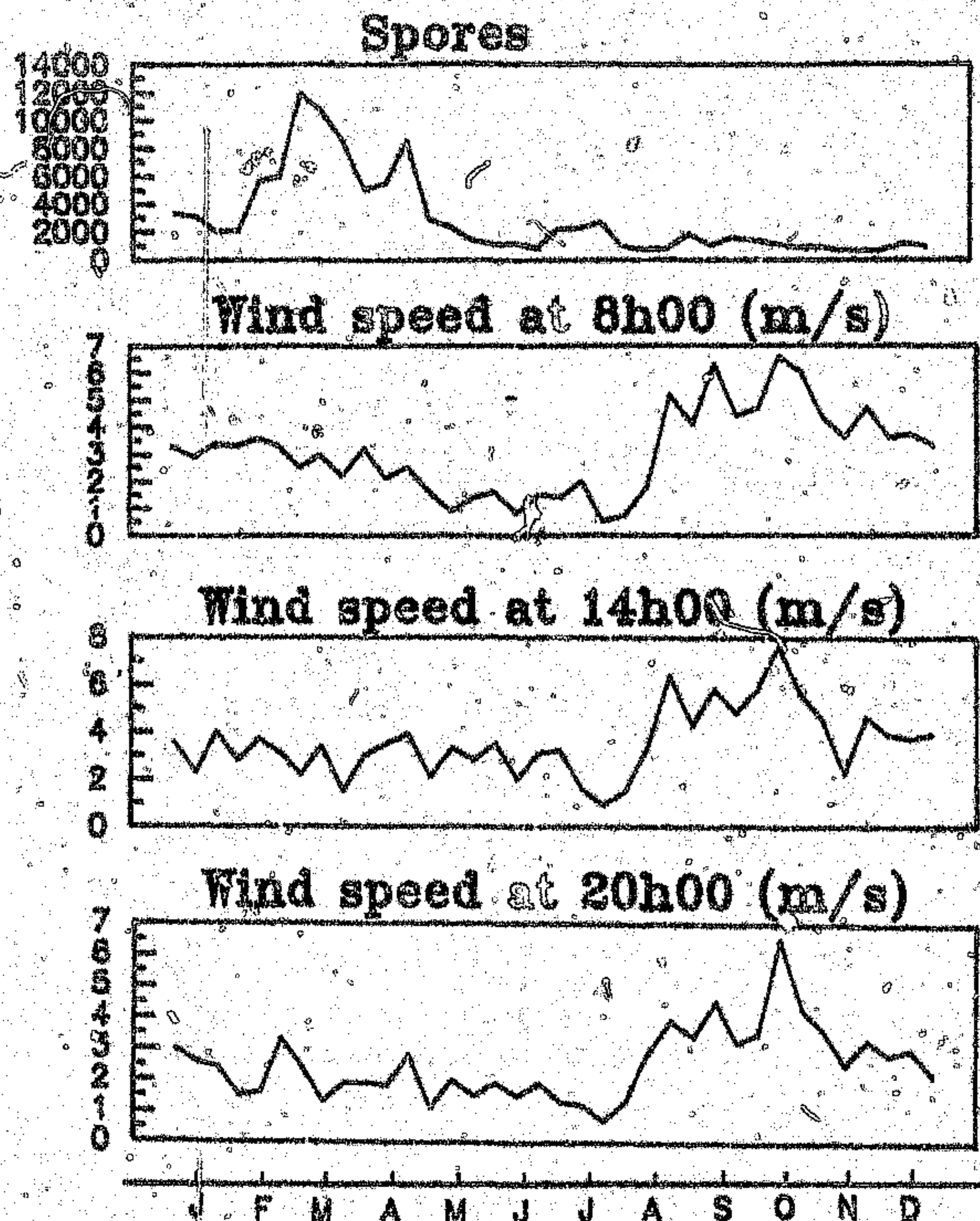

Grass pollen
120
100
80
60
40
20
0
Rainfall (mm)
100
80
60
40
20
0
Global radiation (MJ/m²)
30
25
20
15
10
Diffuse radiation (MJ/m²)
12
10
8
6
4
2
0
J F M A M J J A S O N D

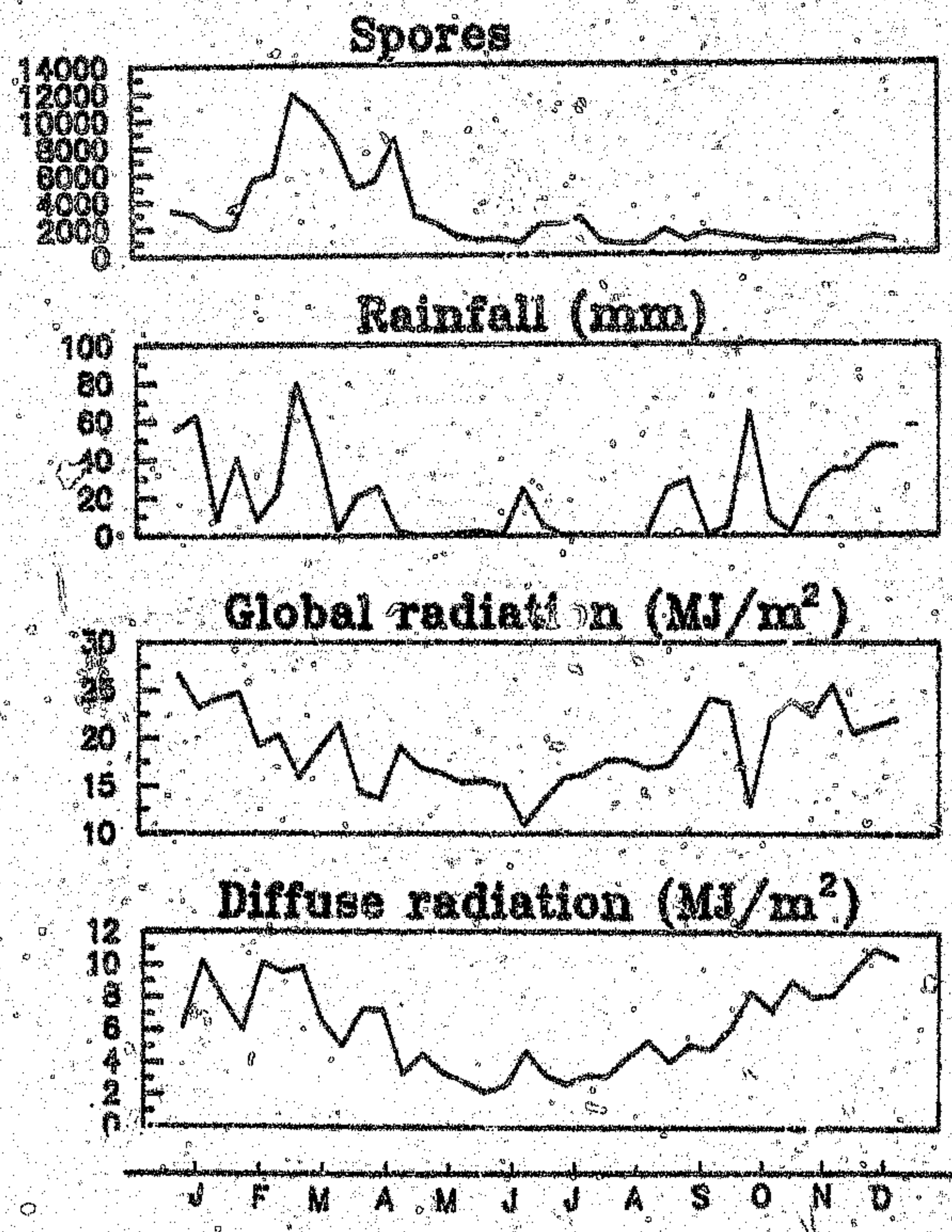
Appendix 1d Spores and meteorological parameters in Johannesburg, 1988.



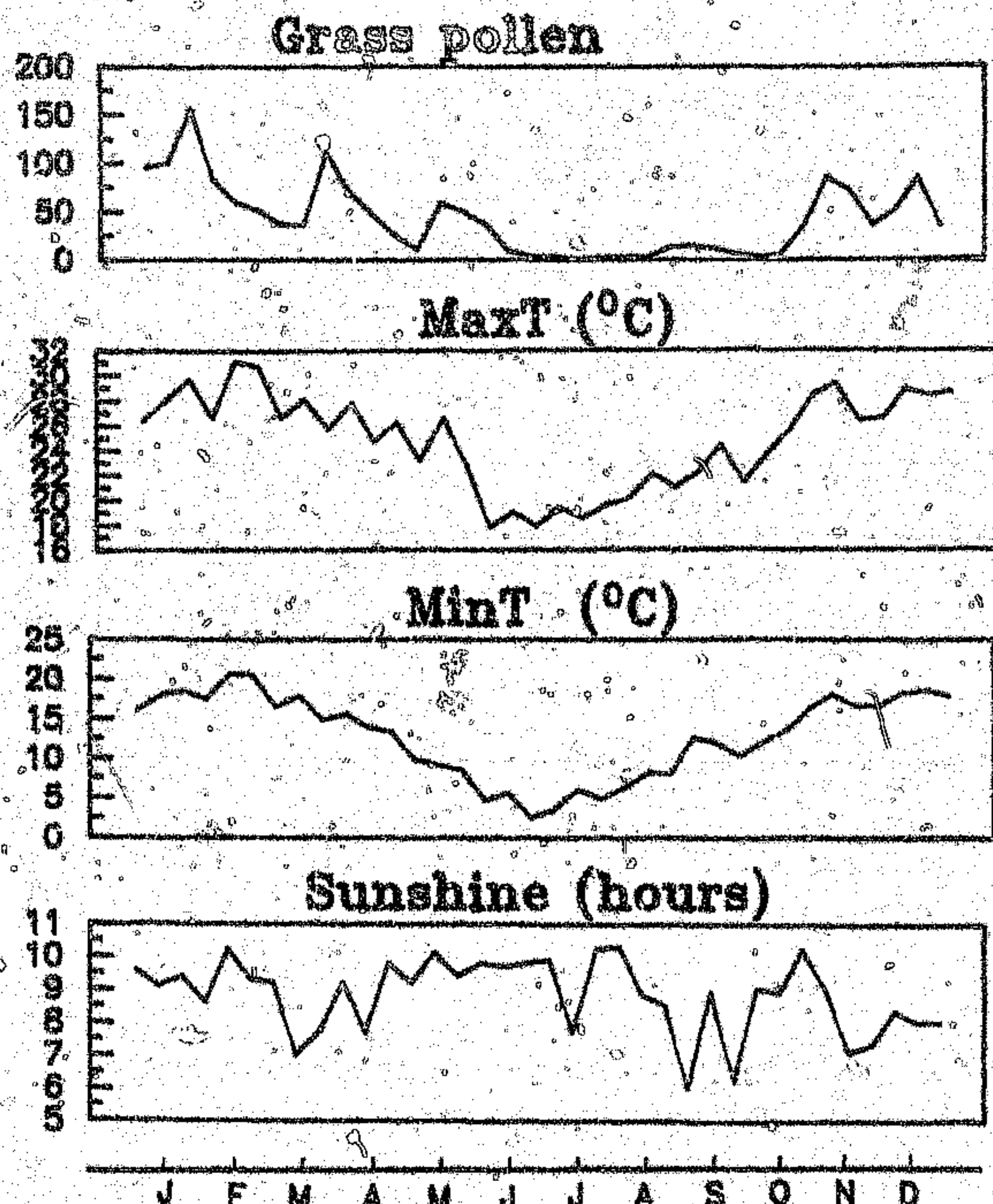

Spores
14000
12000
10000
8000
6000
4000
2000
0
P at 8h00 (mb)
840
838
836
834
832
830
828
P at 14h00 (mb)
840
838
836
834
832
830
828
P at 20h00 (mb)
840
838
836
834
832
830
828
J
F
M
A
M
J
J
A
S
O
N
D

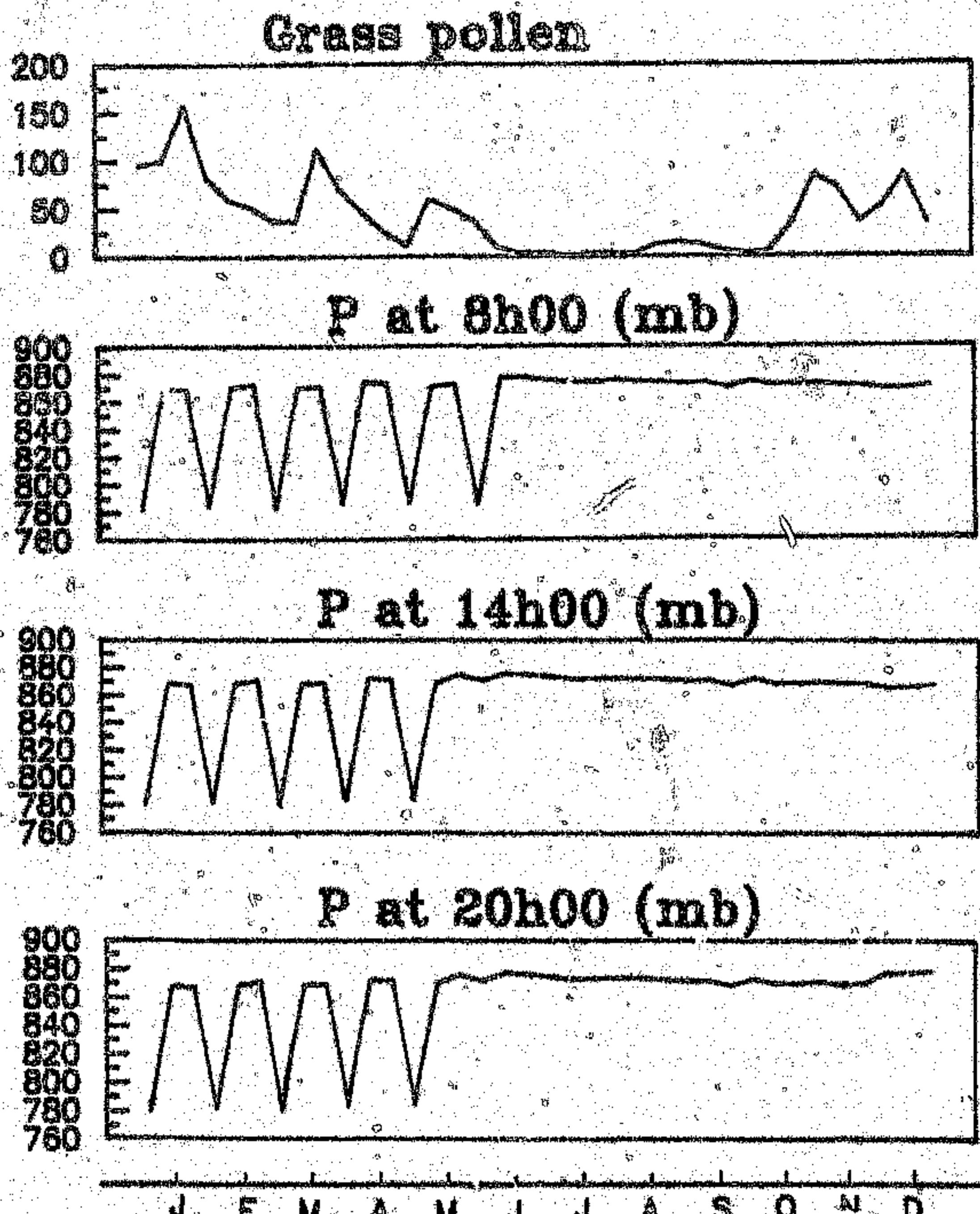

Spores
14000
12000
10000
8000
6000
4000
2000
0
rh at 8h00 (%)
10
9
8
7
6
5
4
rh at 14h00 (mb)
7
6
5
4
3
2
1
rh at 20h00 (mb)
9
8
7
6
5
4
3
2
J F M A M J J A S O N D

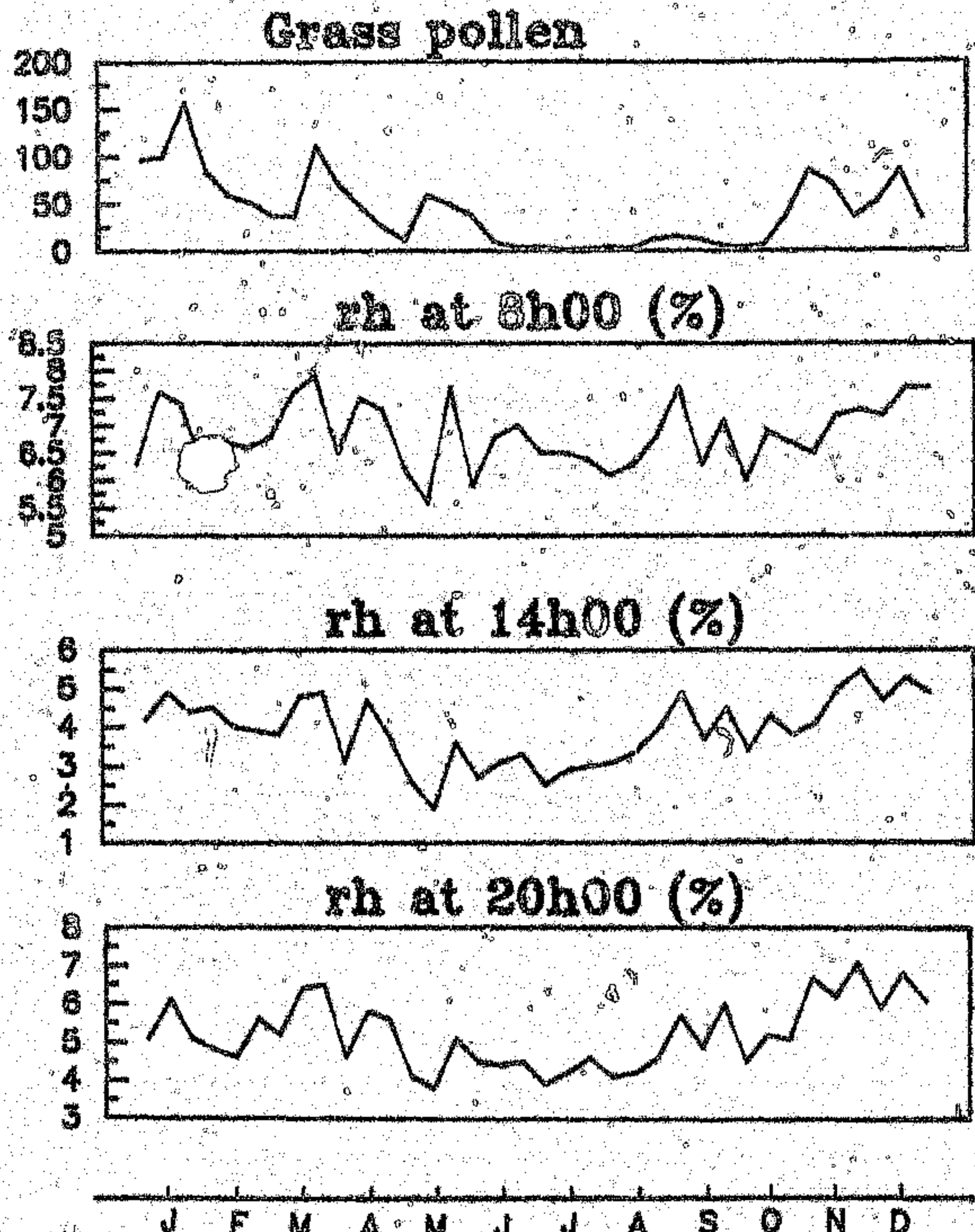

Spores
14000
12000
10000
8000
6000
4000
2000
0
Wind speed at 8h00 (m/s)
7
6
5
4
3
2
1
0
Wind speed at 14h00 (m/s)
8
6
4
2
0
Wind speed at 20h00 (m/s)
7
6
5
4
3
2
1
0
J F M A M J J A S O N D

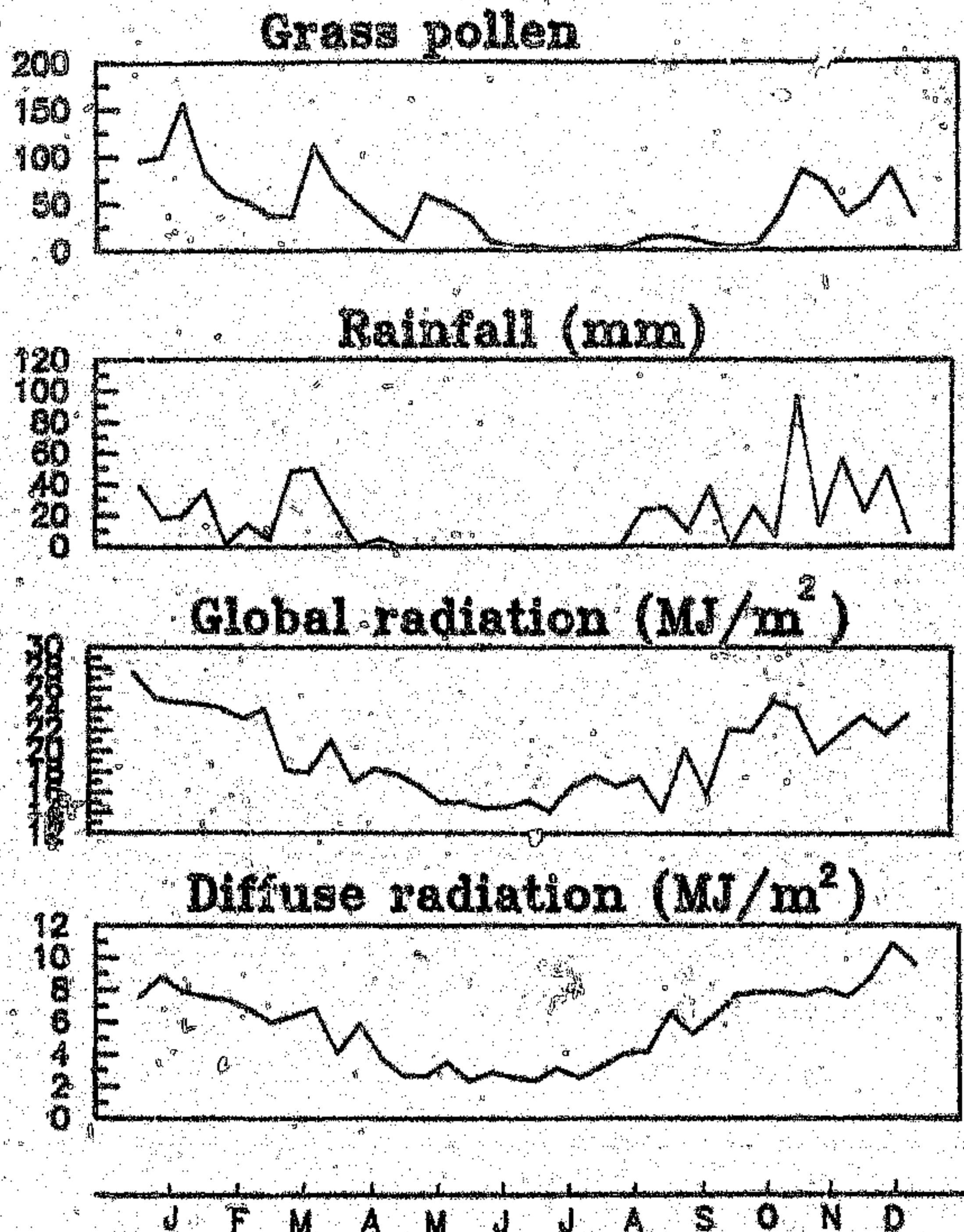

Spores
14000
12000
10000
8000
6000
4000
2000
0
Rainfall (mm)
100
80
60
40
20
0
Global radiation (MJ/m2)
30
25
20
15
10
Diffuse radiation (MJ/m2)
12
10
8
6
4
2
0
J F M A M J J A S O N D

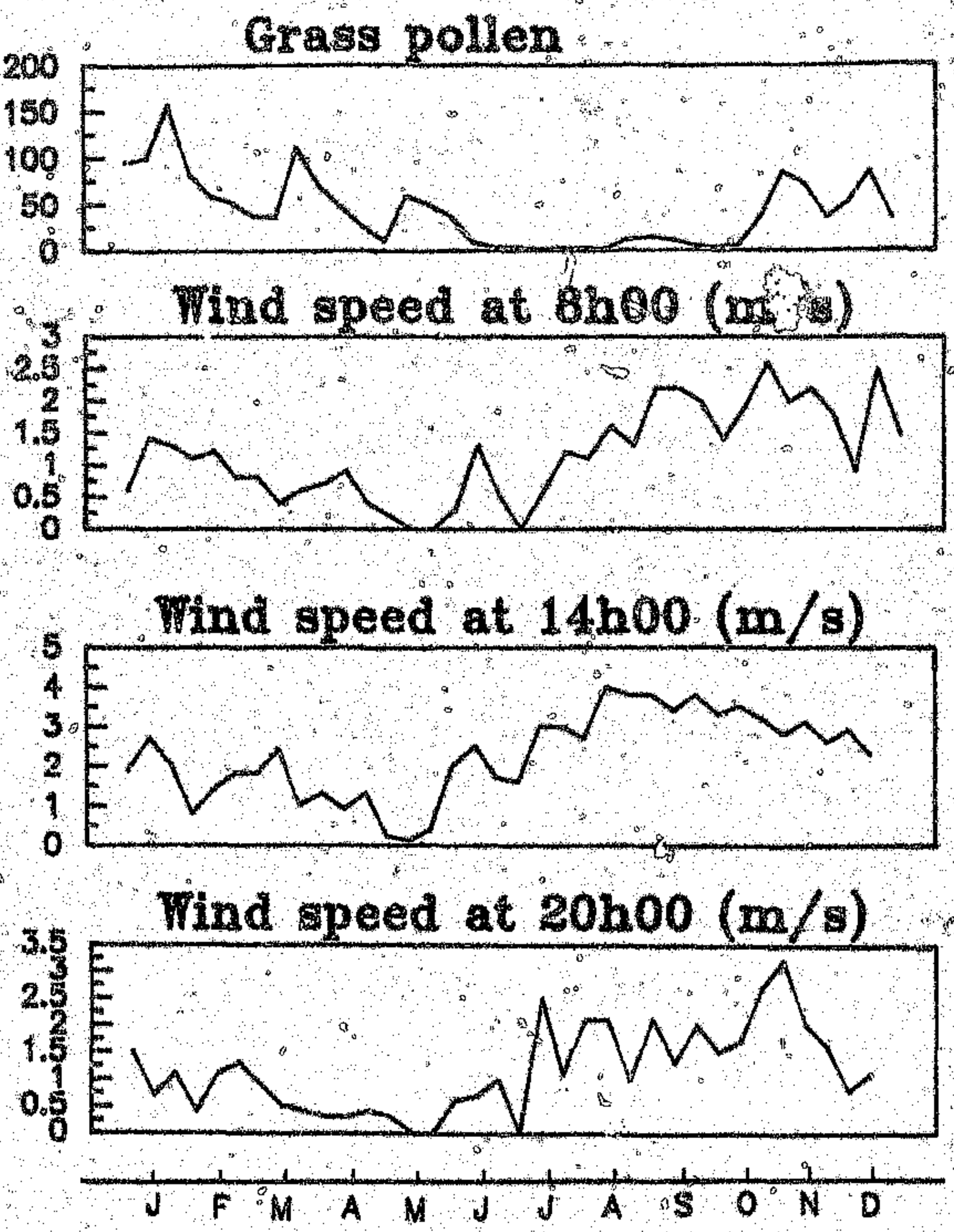
Appendix 1e Grass pollen and meteorological parameters in Pretoria, 1987.



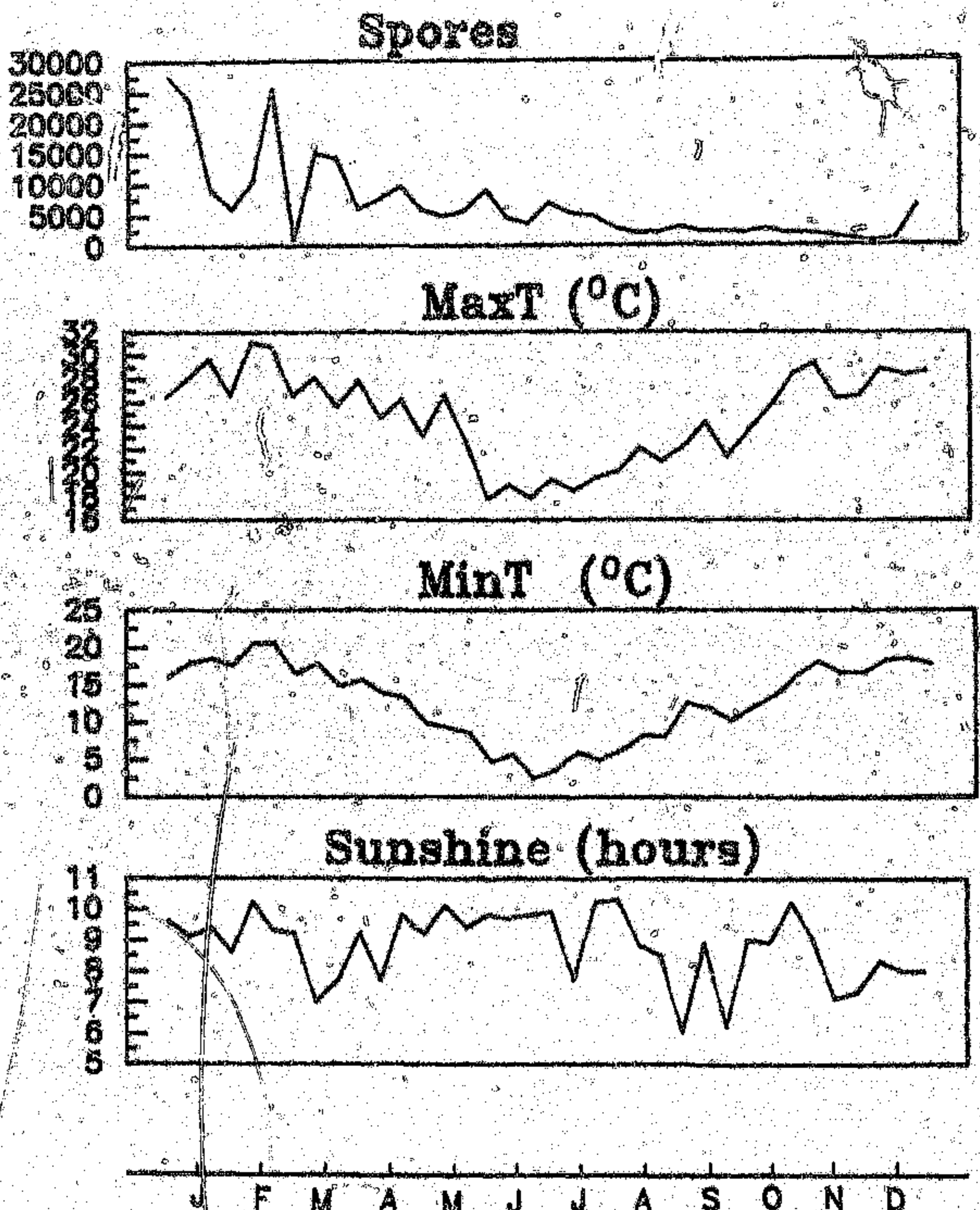

Grass pollen
200
150
100
50
0
P at 8h00 (mb)
900
880
860
840
820
800
780
760
P at 14h00 (mb)
900
880
860
840
820
800
780
760
P at 20h00 (mb)
900
880
860
840
820
800
780
760
J F M A M J J A S O N D

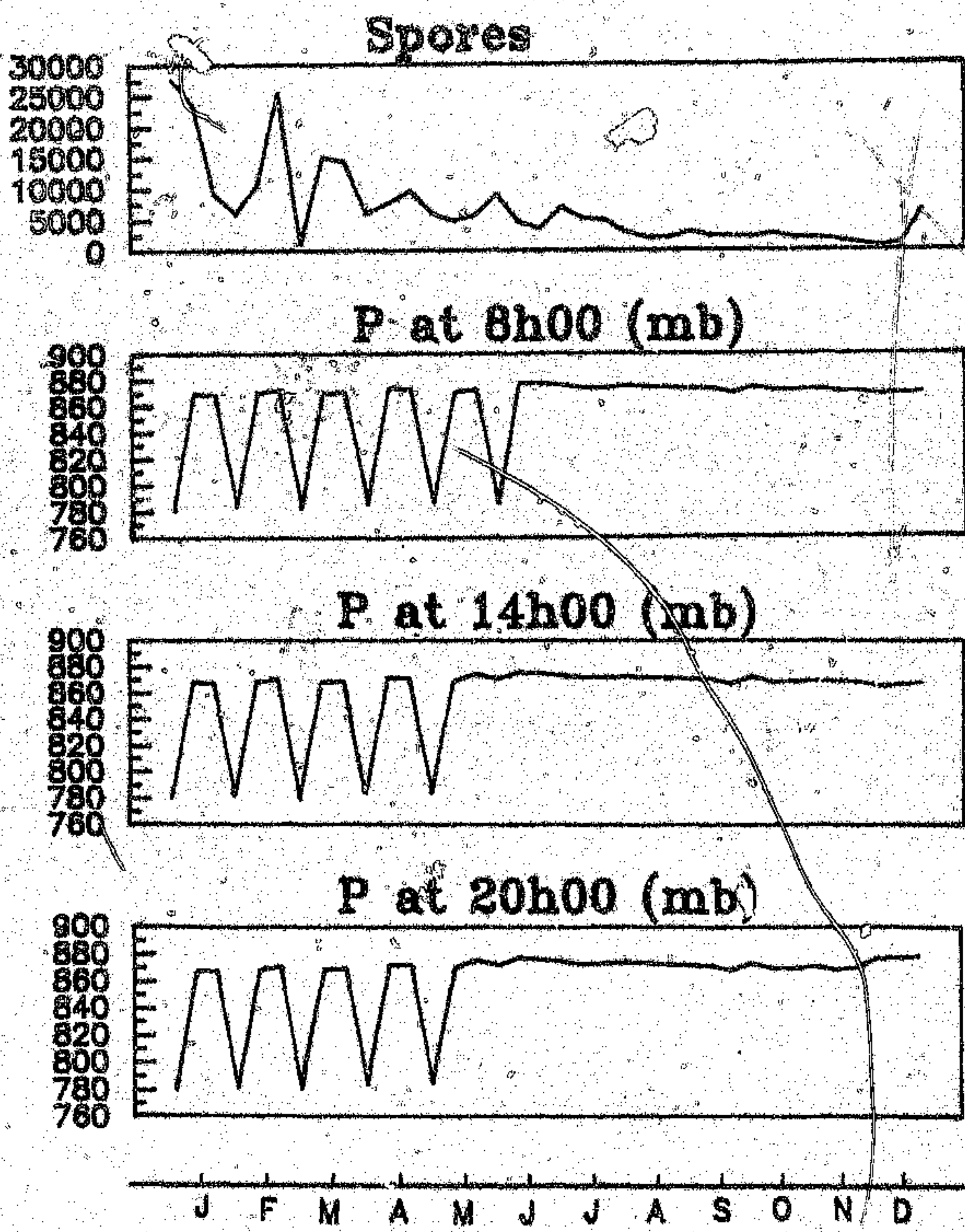

Grass pollen
200
150
100
50
0
rh at 8h00 (%)
8.5
8
7.5
7
6.5
6
5.5
5
rh at 14h00 (%)
6
5
4
3
2
1
rh at 20h00 (%)
8
7
6
5
4
3
J F M A M J J A S O N D

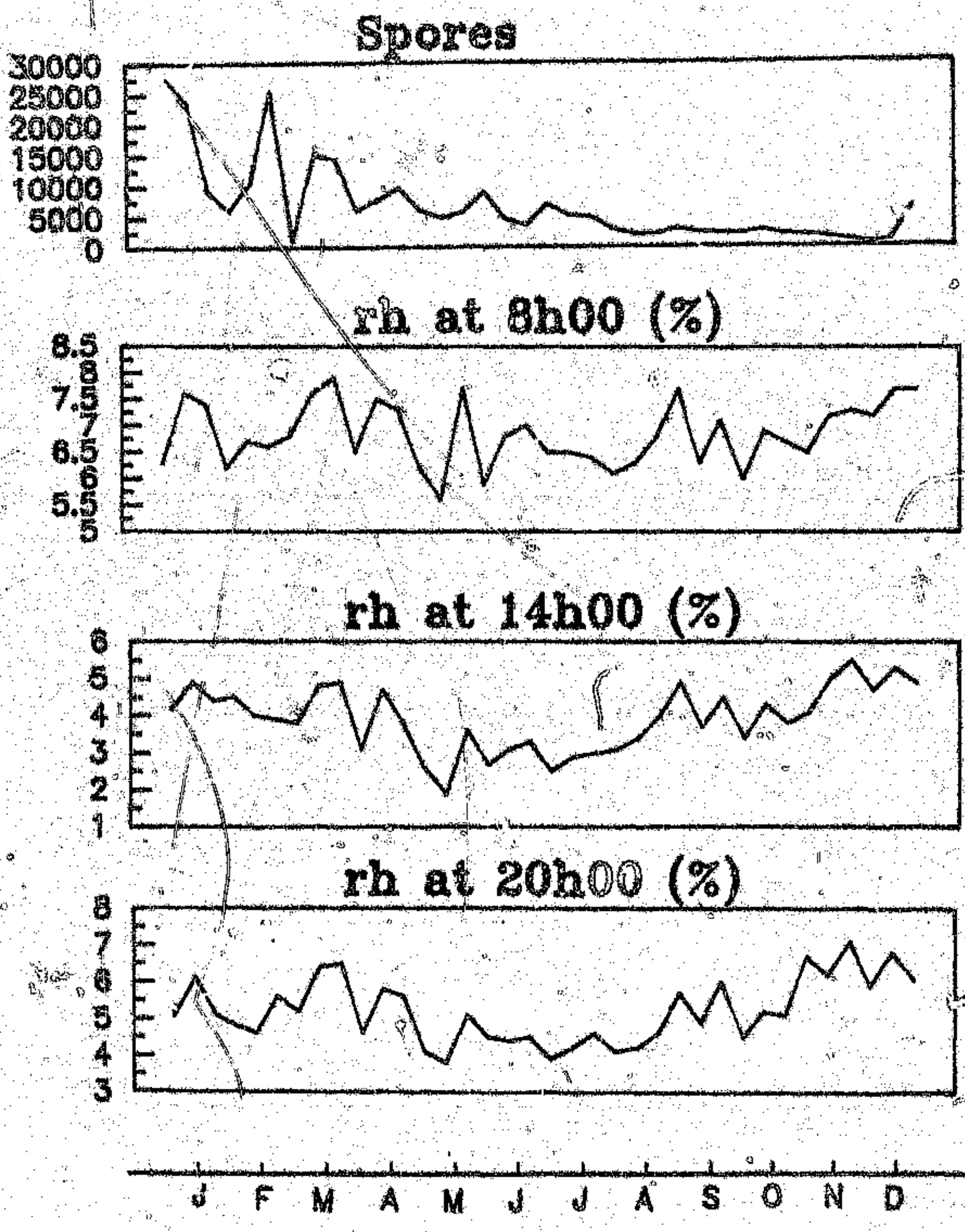

Grass pollen
200
150
100
50
0
Rainfall (mm)
120
100
80
60
40
20
0
Global radiation (MJ/m2)
Diffuse radiation (MJ/m2)
12
10
8
6
4
2
0
J F M A M J J A S O N D

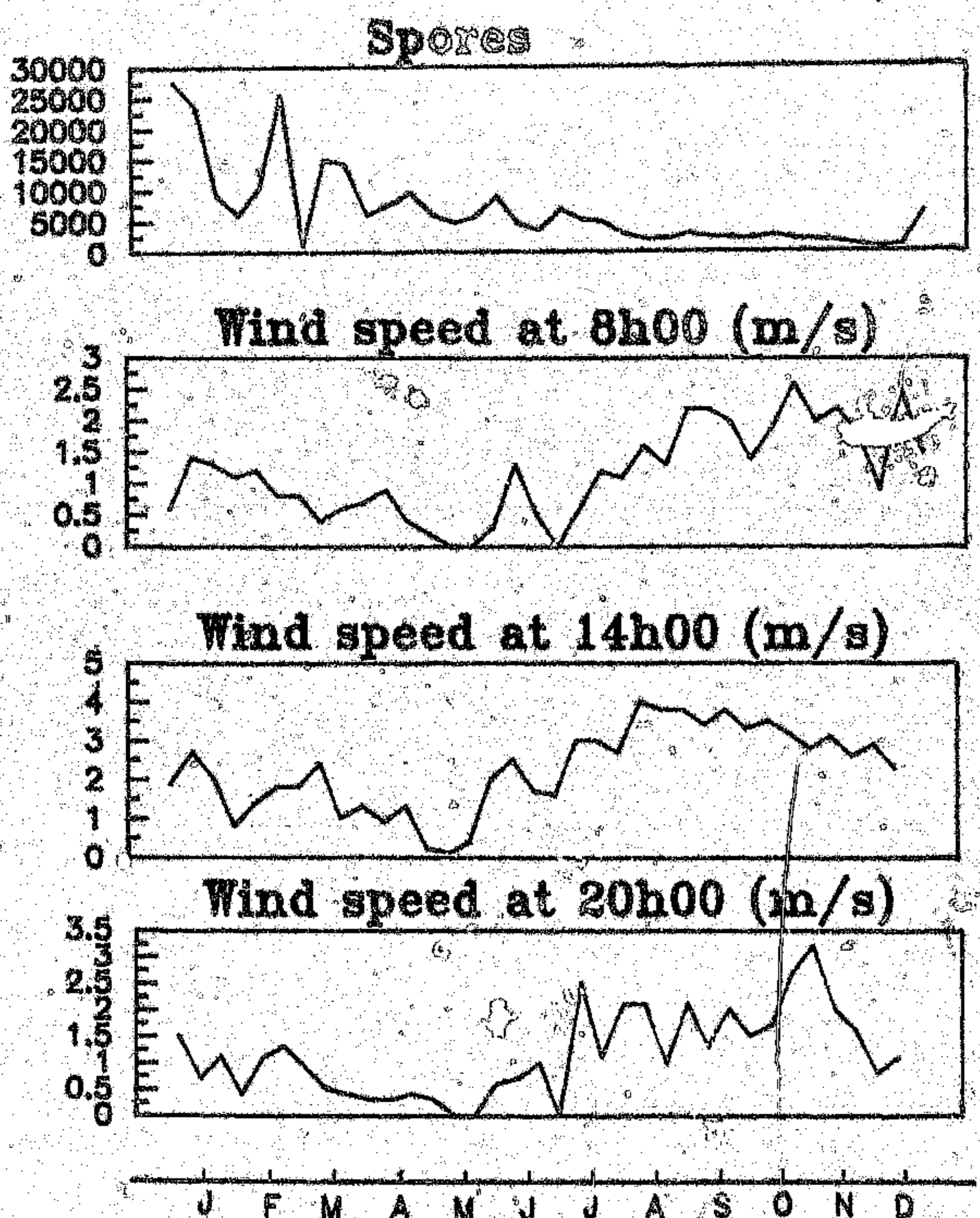

Grass pollen
200
150
100
50
0
Wind speed at 8h00 (m/s)
3
2.5
2
1.5
1
0.5
0
Wind speed at 14h00 (m/s)
5
4
3
2
1
0
Wind speed at 20h00 (m/s)
3.5
2.5
1.5
0.5
0
J F M A M J J A S O N D

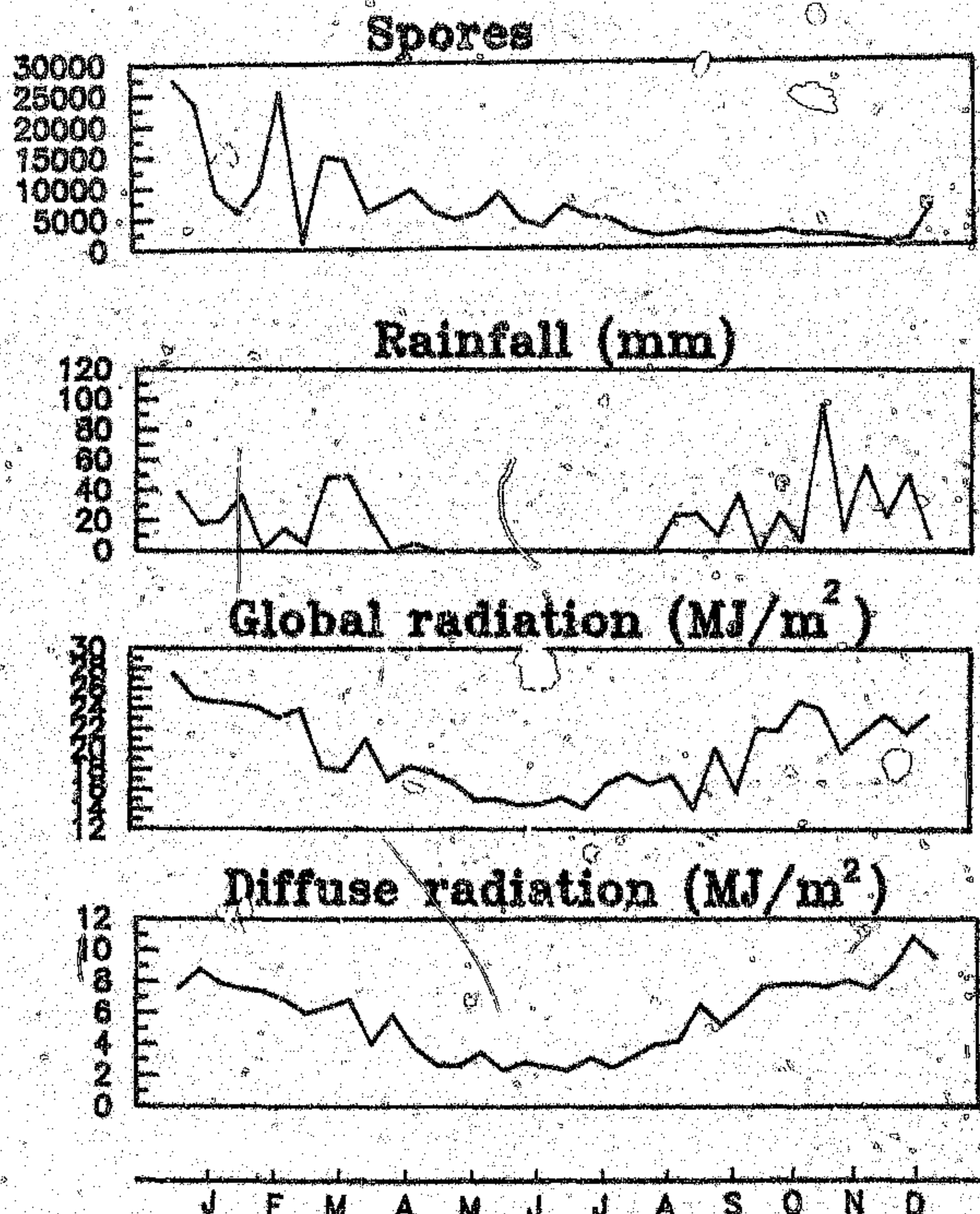
Appendix 1f Spores and meteorological parameters in Pretoria, 1987.



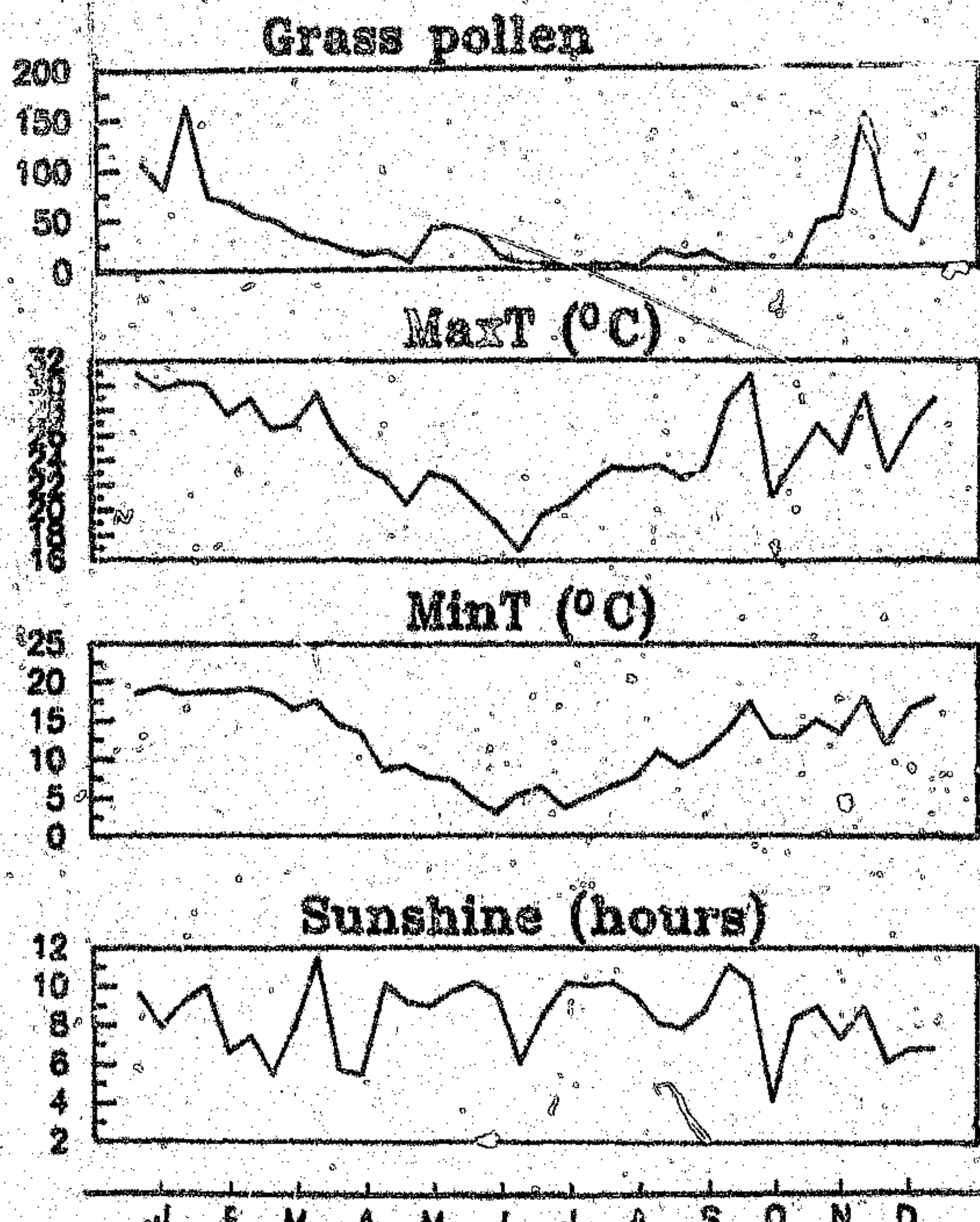

Spores
30000
25000
20000
15000
10000
5000
0
P at 8h00 (mb)
900
880
860
840
820
800
780
760
P at 14h00 (mb)
900
880
860
840
820
800
780
760
P at 20h00 (mb)
900
880
860
840
820
800
780
760
J F M A M J J A S O N D

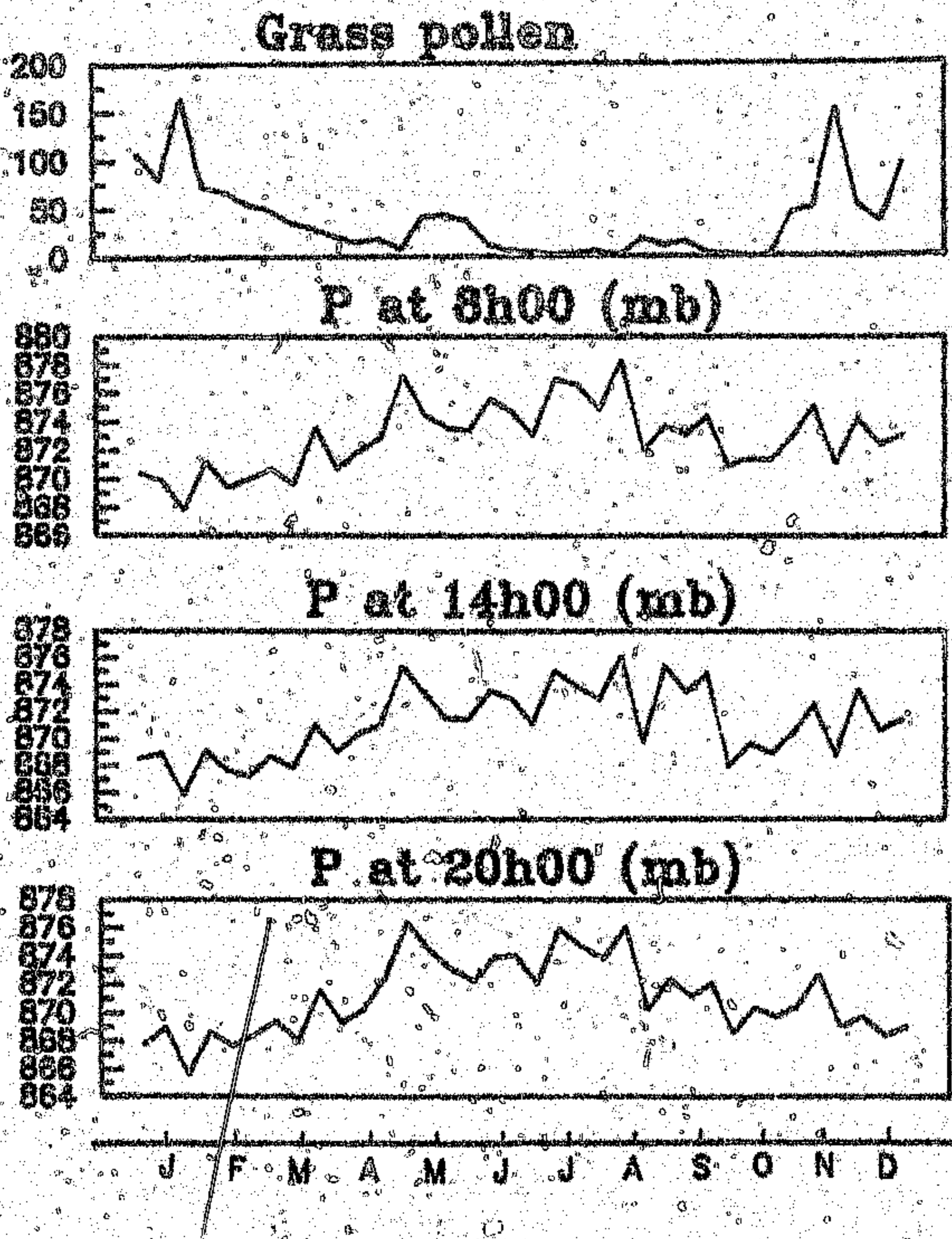

Spores
30000
25000
20000
15000
10000
5000
0
rh at 8h00 (%)
8.5
8
7.5
7
6.5
6
5.5
5
rh at 14h00 (%)
6
5
4
3
2
1
rh at 20h00 (%)
8
7
6
5
4
3
J F M A M J J A S O N D

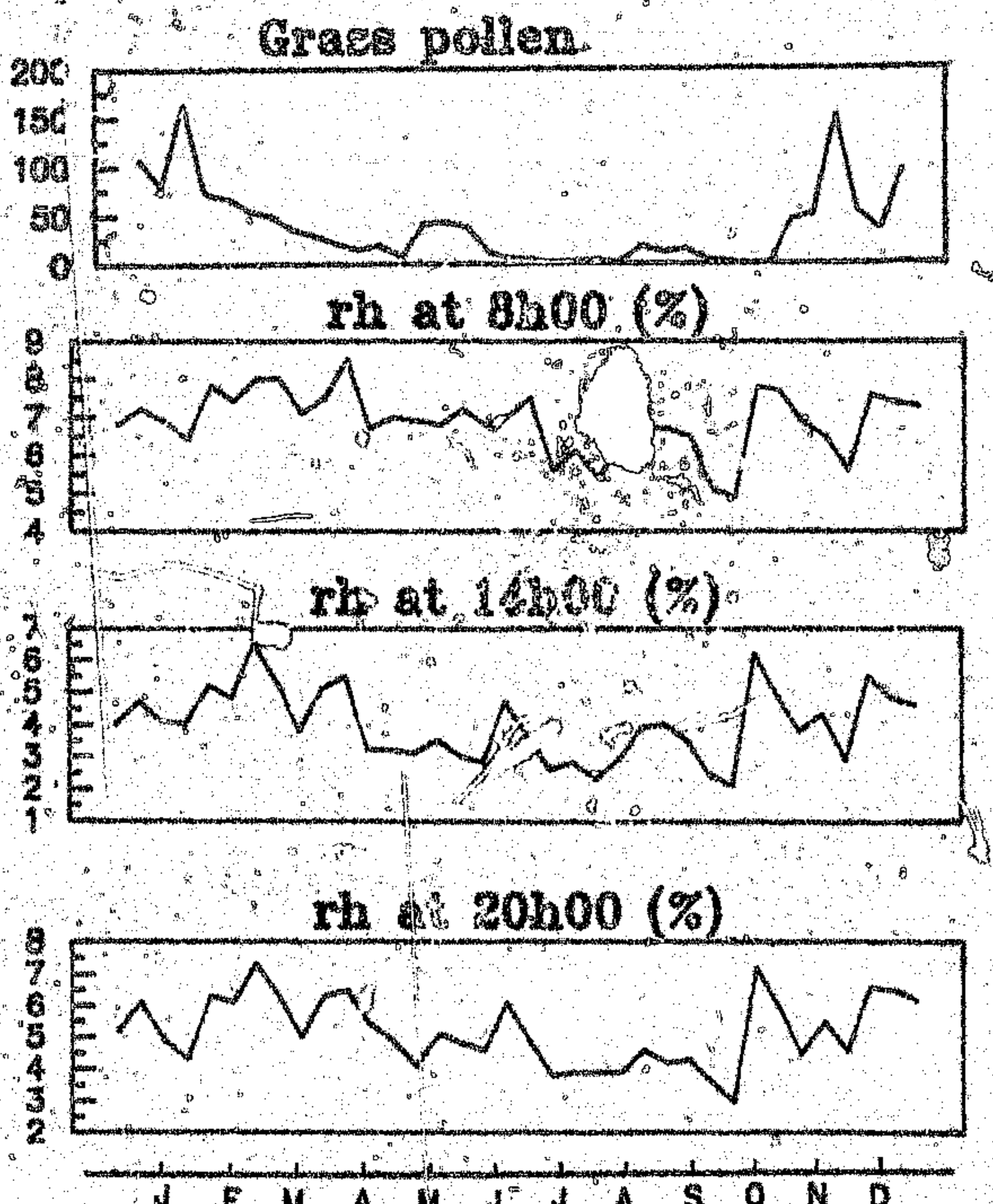

Spores
30000
25000
20000
15000
10000
5000
0
Wind speed at 8h00 (m/s)
3
2.5
2
1.5
1
0.5
0
Wind speed at 14h00 (m/s)
5
4
3
2
1
0
Wind speed at 20h00 (m/s)
3.5
2.5
1.5
0.5
0
J
F
M
A
M
J
J
A
S
O
N
D

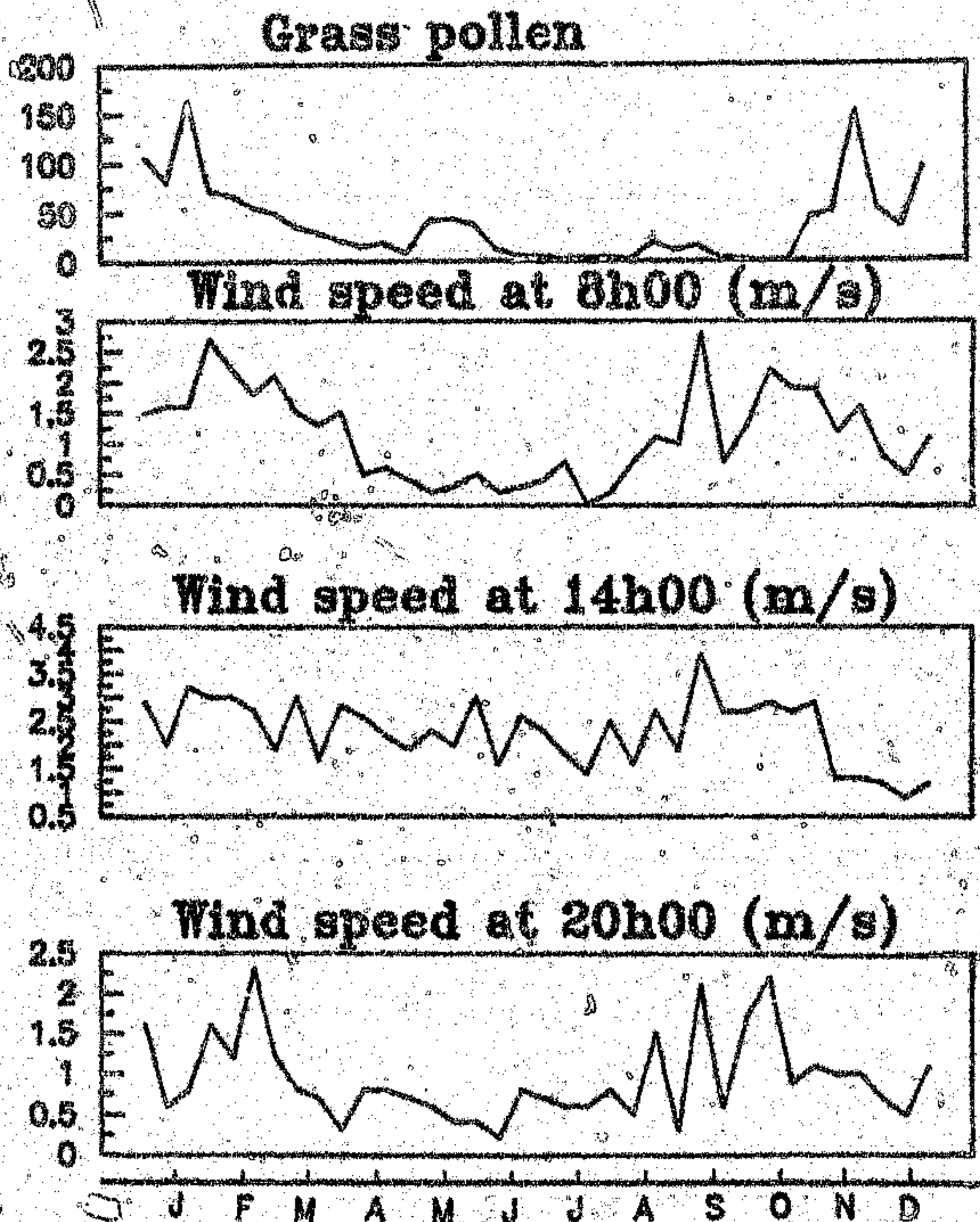

Spores
30000
25000
20000
15000
10000
5000
0
Rainfall (mm)
120
100
80
60
40
20
0
Global radiation (MJ/m²)
30
28
26
24
22
20
18
16
14
12
Diffuse radiation (MJ/m²)
12
10
8
6
4
2
0
J F M A M J J A S O N D

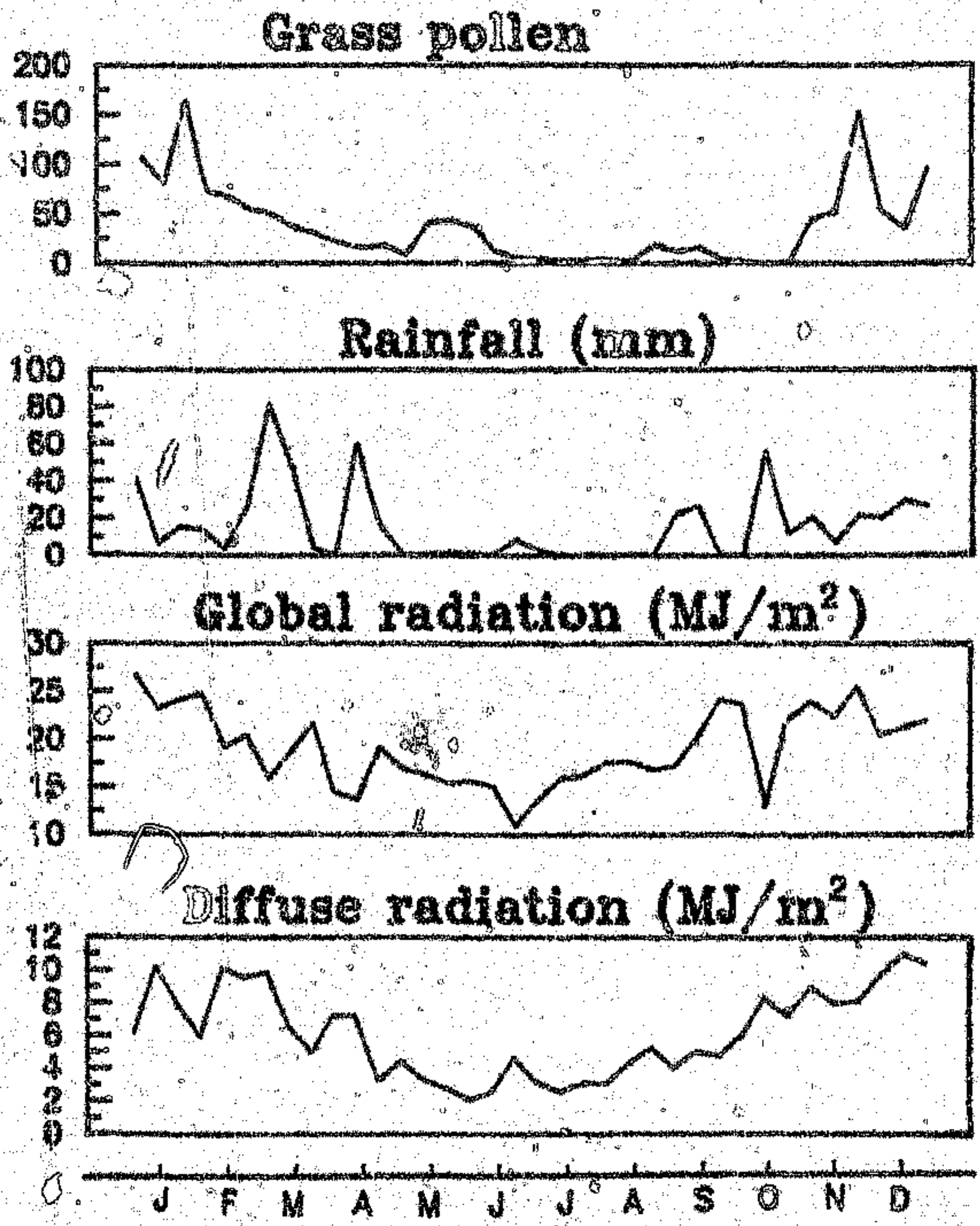
Appendix 1g Grass pollen and meteorological parameters in Pretoria, 1988.



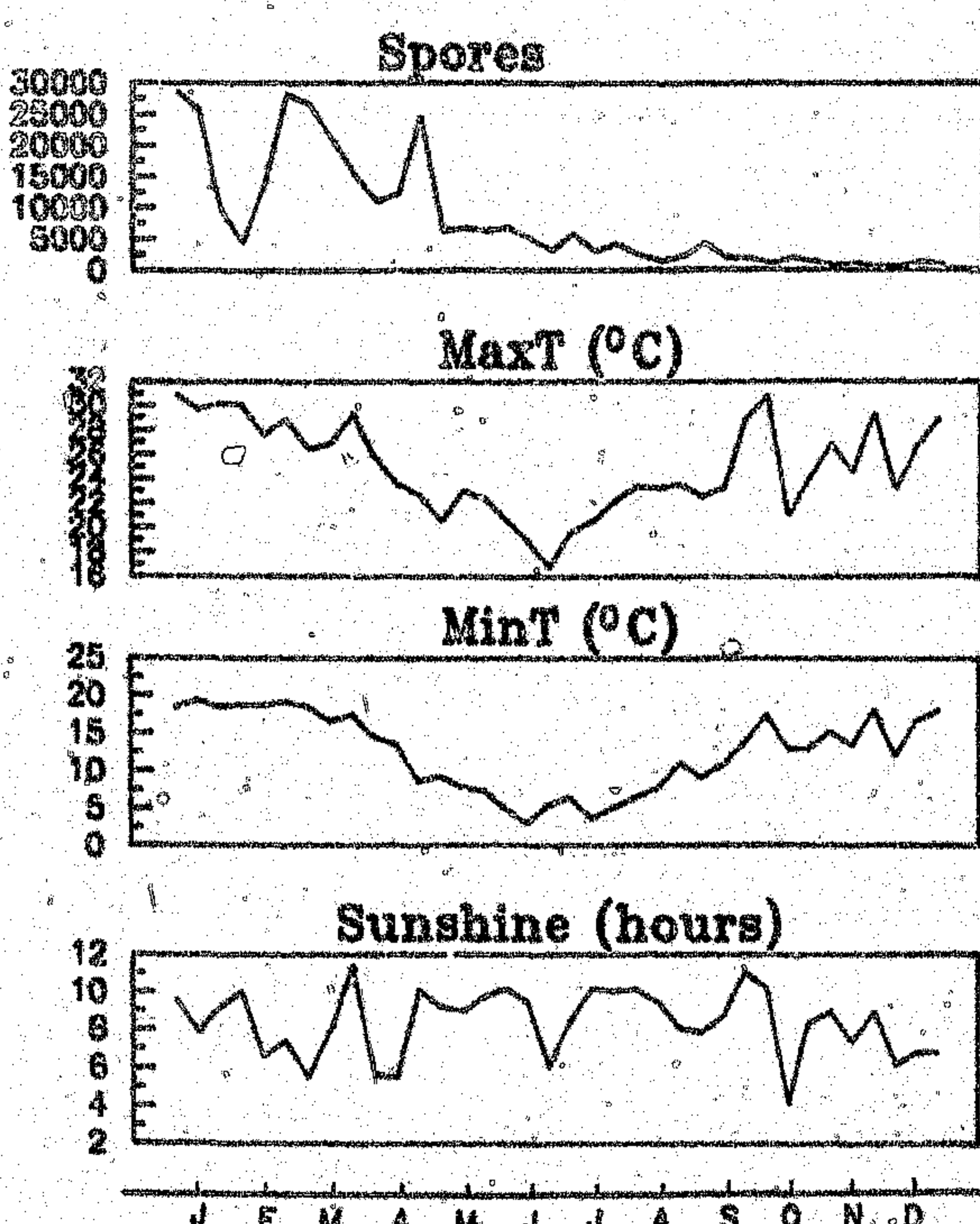

Grass pollen
200
150
100
50
0
P at 8h00 (mb)
880
878
876
874
872
870
868
866
P at 14h00 (mb)
878
876
874
872
870
868
866
864
P at 20h00 (mb)
878
876
874
872
870
868
866
864
J F M A M J J A S O N D

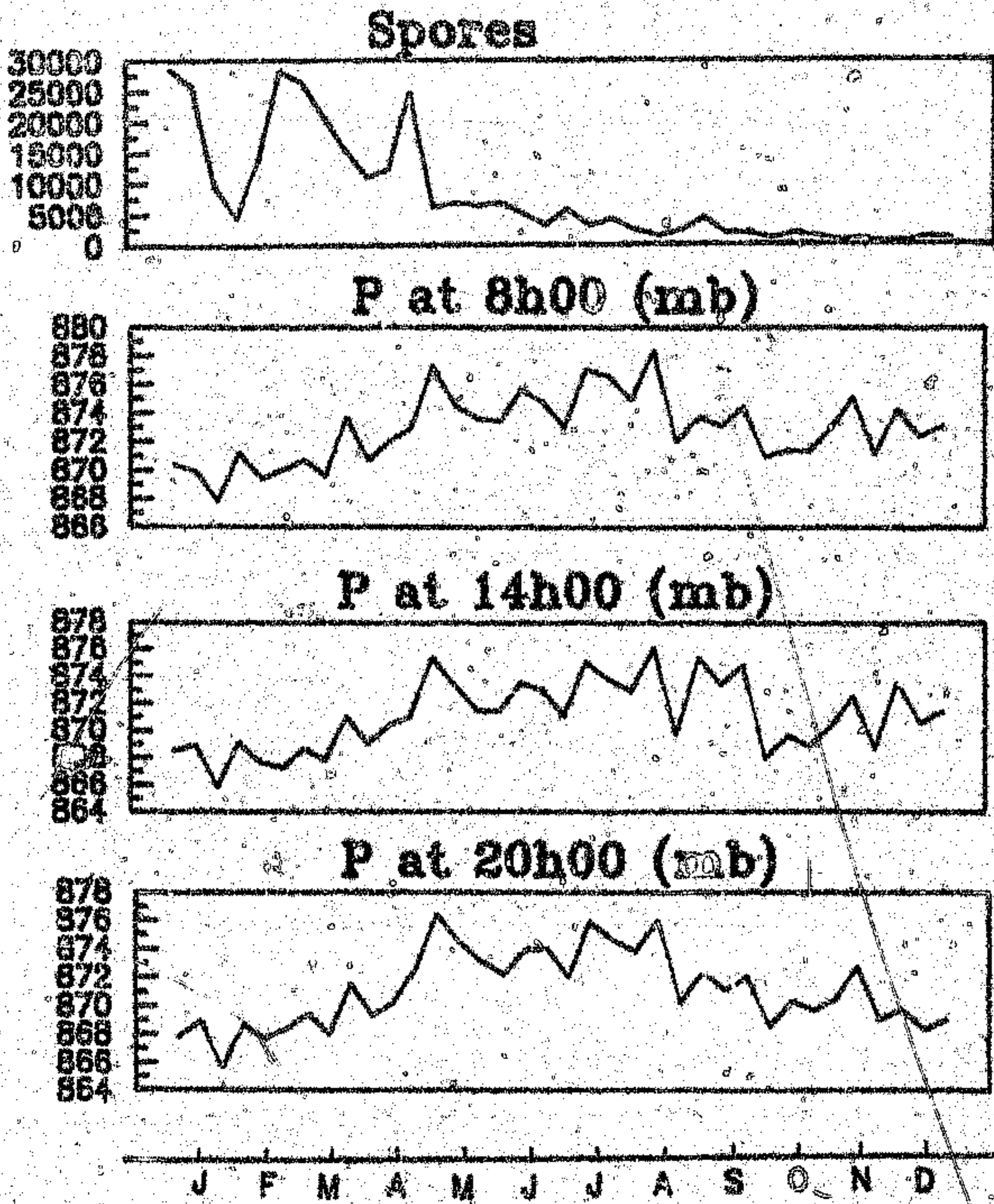

Grass pollen
200
150
100
50
0
rh at 8h00 (%)
9
8
7
6
5
4
rh at 14h00 (%)
7
6
5
4
3
2
1
rh at 20h00 (%)
8
7
6
5
4
3
2
J F M A M J J A S O N D

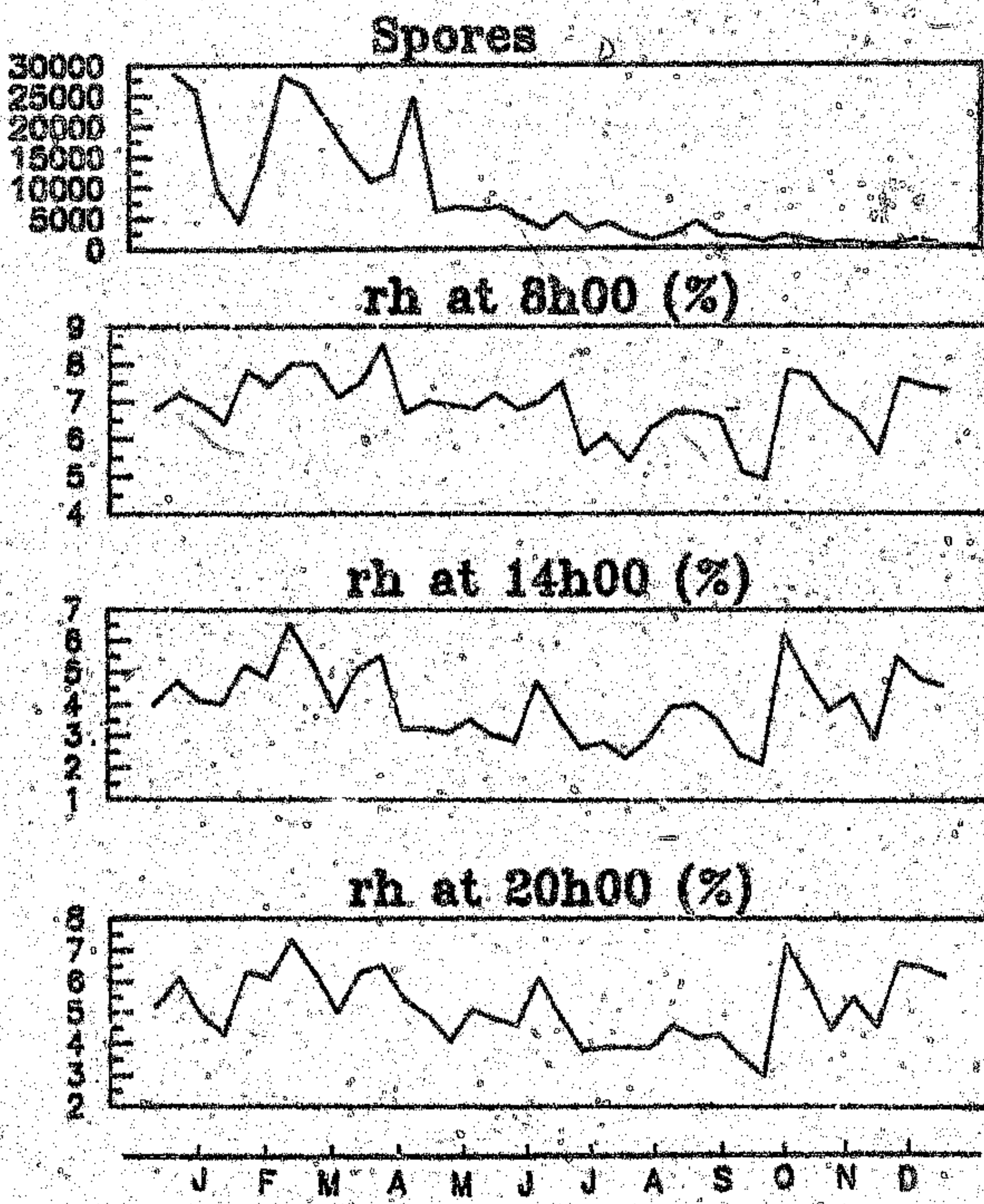

Grass pollen
200
150
100
50
0
Wind speed at 8h00 (m/s)
3
2.5
2
1.5
1
0.5
0
Wind speed at 14h00 (m/s)
4.5
3.5
2.5
1.5
0.5
Wind speed at 20h00 (m/s)
2.5
2
1.5
1
0.5
0
J F M A M J J A S O N D

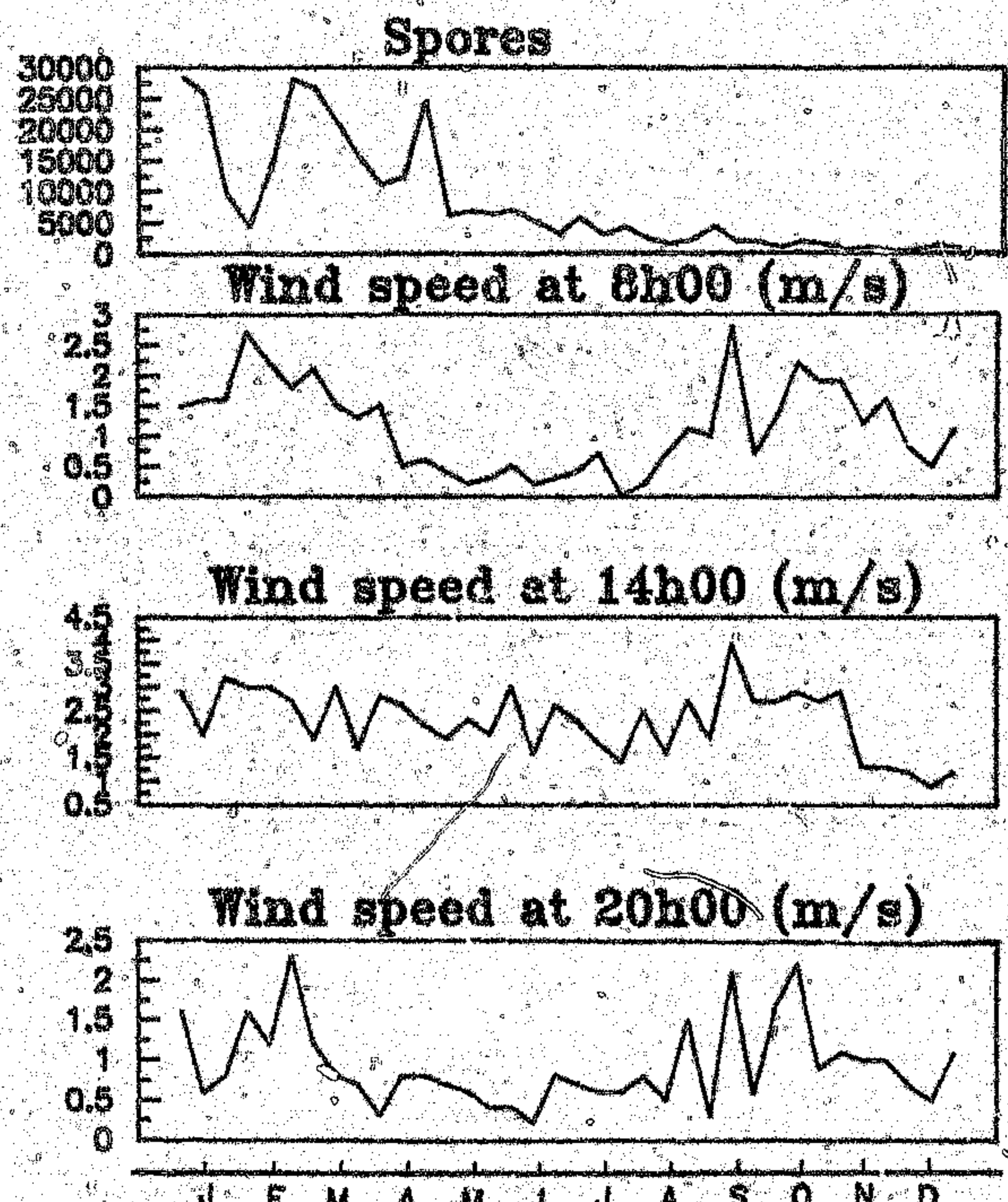

Grass pollen
200
150
100
50
0
Rainfall (mm)
100
80
60
40
20
0
Global radiation (MJ/m²)
30
25
20
15
10
Diffuse radiation (MJ/m²)
12
10
8
6
4
2
0
J F M A M J J A S O N D

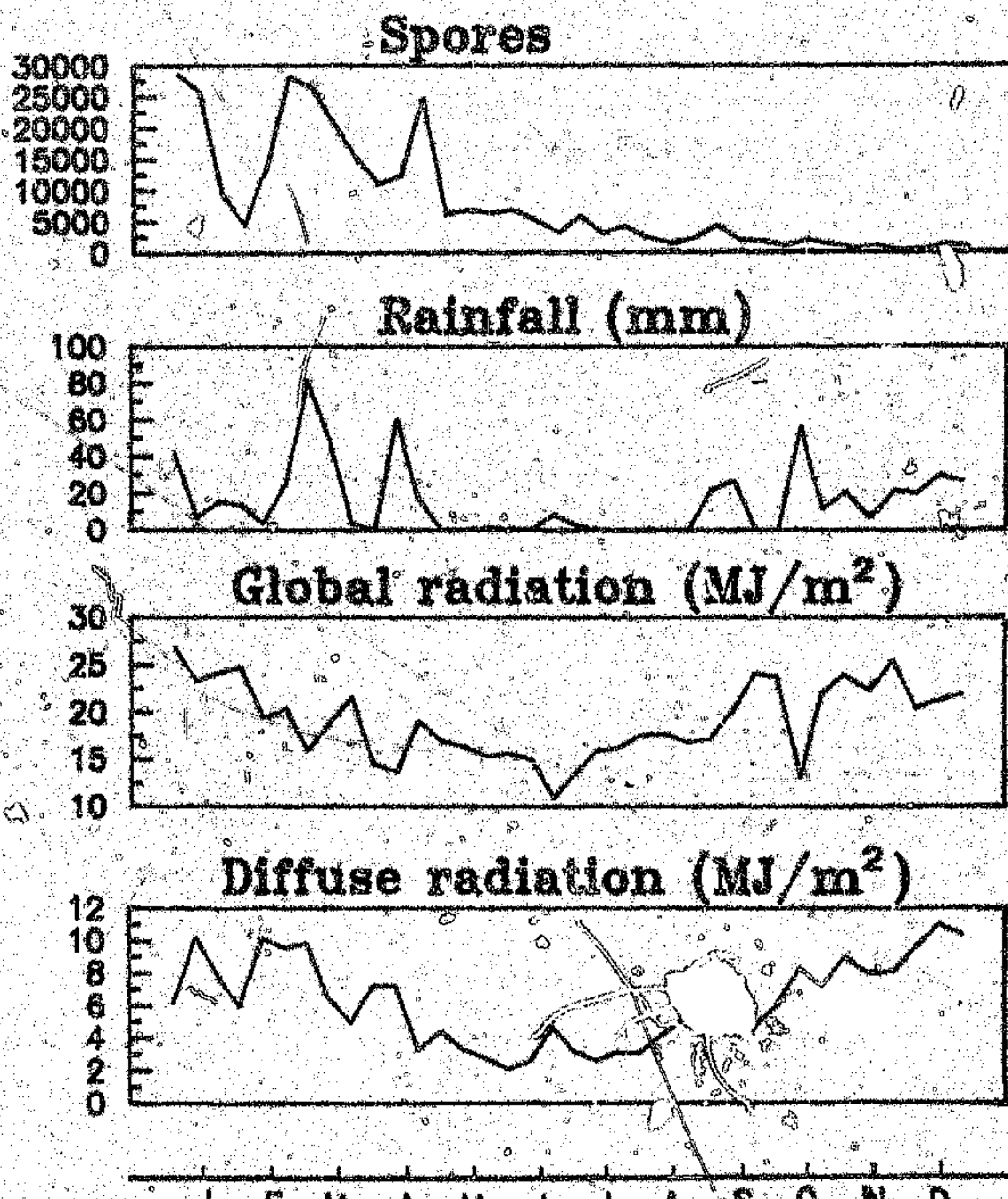
Appendix 1h Spores and meteorological parameters in Pretoria, 1980.




Spores
30000
25000
20000
15000
10000
5000
0
P at 8h00 (mb)
880
878
876
874
872
870
868
866
P at 14h00 (mb)
878
876
874
872
870
866
864
P at 20h00 (mb)
878
876
874
872
870
868
866
864
J F M A M J J A S O N D


Spores
30000
25000
20000
15000
10000
5000
0
rh at 8h00 (%)
9
8
7
6
5
4
rh at 14h00 (%)
7
6
5
4
3
2
1
rh at 20h00 (%)
8
7
6
5
4
3
2
J F M A M J J A S O N D


Spores
30000
25000
20000
15000
10000
5000
0
Wind speed at 8h00 (m/s)
3
2.5
2
1.5
1
0.5
0
Wind speed at 14h00 (m/s)
4.5
0.5
Wind speed at 20h00 (m/s)
2.5
2
1.5
1
0.5
0
J F M A M J J A S O N D


Spores
30000
25000
20000
15000
10000
5000
0
Rainfall (mm)
100
80
60
40
20
0
Global radiation (MJ/m²)
30
25
20
15
10
Diffuse radiation (MJ/m²)
12
10
8
6
4
2
0
J F M A M J J A S O N D

Appendix 2 Correlation coefficients of airspora and meteorological factors in Johannesburg and Pretoria, 1987-1988.

	Johannesburg		Pretoria	
	Grass Pollen	Spores	Grass Pollen	Spores
Maximum temperature	0.50	0.23	0.64	0.31
Minimum temperature	0.48	0.38	0.63	0.34
Rainfall	0.37	0.17	0.33	0.24
Pressure at 8h00	-0.35	-0.20	-0.18	-0.11
Pressure at 14h00	-0.38	-0.21	-0.20	-0.10
Pressure at 20h00	-0.42	-0.23	-0.20	-0.11
Relative humidity at 8h00	0.15	0.30	0.16	0.29
Relative humidity at 14h00	0.30	0.28	0.27	0.26
Relative humidity at 20h00	0.29	0.27	0.28	0.29
Windspeed at 8h00	0.02	-0.32	0.20	-0.04
Windspeed at 14h00	-0.12	-0.36	-0.22	-0.07
Windspeed at 20h00	-0.13	-0.39	-0.02	-0.07
Sunhours	0.02	-0.12	-0.01	-0.02
Radiation, global	0.51	0.03	0.60	0.17
Radiation, diffuse	0.37	0.06	0.50	0.17

Appendix 3 Stepwise multiple regression analysis of airspora on meteorological factors

(where MaxT = maximum temperature
MinT = minimum temperature
Rain = rainfall
Pat8 = pressure at 8h00
Pat14 = pressure at 14h00
Pat20 = pressure at 20h00
rhat8 = relative humidity at 8h00
rhat14 = relative humidity at 14h00
rhat20 = relative humidity at 20h00
Wndsp8 = windspeed at 8h00
Wndsp14 = windspeed at 14h00
Wndsp20 = windspeed at 20h00
Sunhrs = sunhours
Rdnglbl = radiation, global
Rdndffs = radiation, diffuse).

Appendix 3a   Regression of grass pollen on meteorological variables in Pretoria, 1987-1988.

Stepwise selection for grass pollen in Pretoria

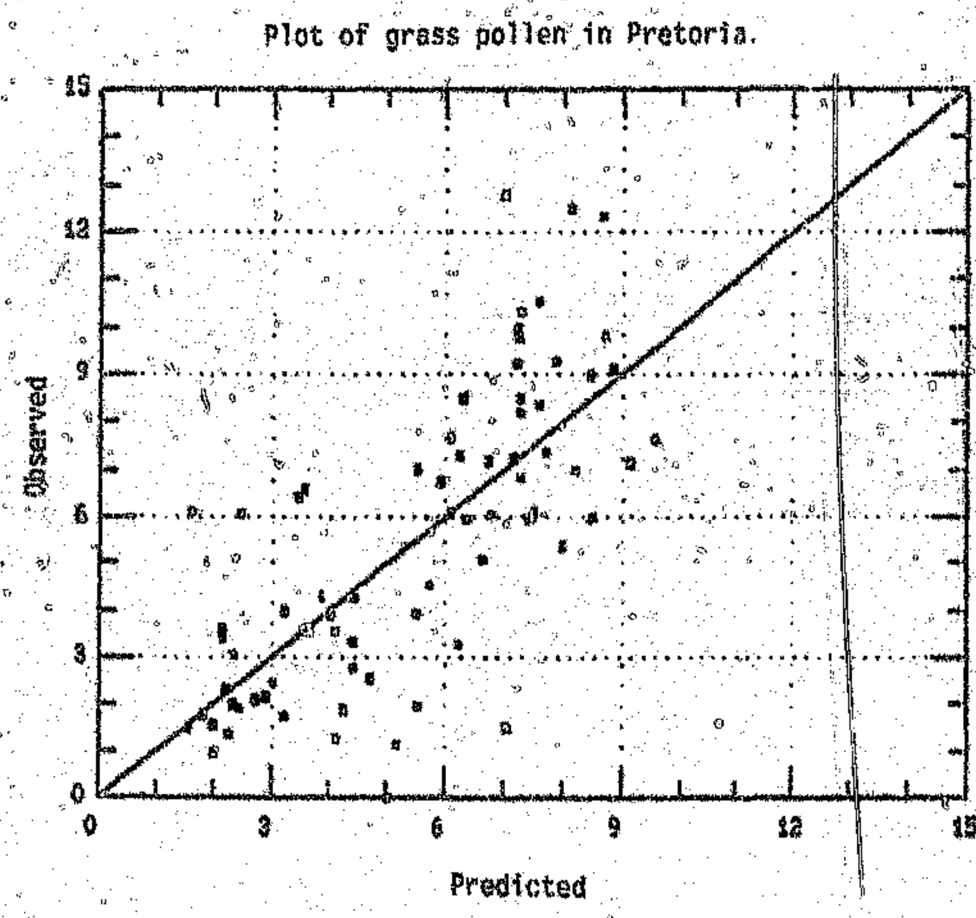
Selection: Forward   Maximum steps: 500   F-to-enter: 4.00
Control: Automatic   Step: 2   F-to-remove: 4.00
R-squared: .52630   Adjusted: .51257   MSE: 4.83206   d.f.: 69

Variables in Model	Coeff.	F-Remove	Variables Not in Model	P.Corr.	F-Enter
8. MPTA.Wndsp14	-0.93863	10.4212	2. MPTA.Pat14	.0014	.0001
11. MPTA.MinT	0.41053	67.1943	3. MPTA.Pat20	.0020	.0003
			7. MPTA.Wndsp8	.0148	.0148
			14. MPTA.Rdndffs	.0238	.0387
			5. MPTA.Whatl4	.0271	.0499
			6. MPTA.Whatl20	.0386	.1015
			4. MPTA.Whatl8	.0839	.4824
			12. MPTA.Rain	.0876	.5253
			1. A:MPTA.Pat8	.0893	.5472
			10. MPTA.MaxT	.1062	.7752
			9. MPTA.Wndsp20	.1277	1.1267
			15. MPTA.Sunhrs	.1342	1.2469

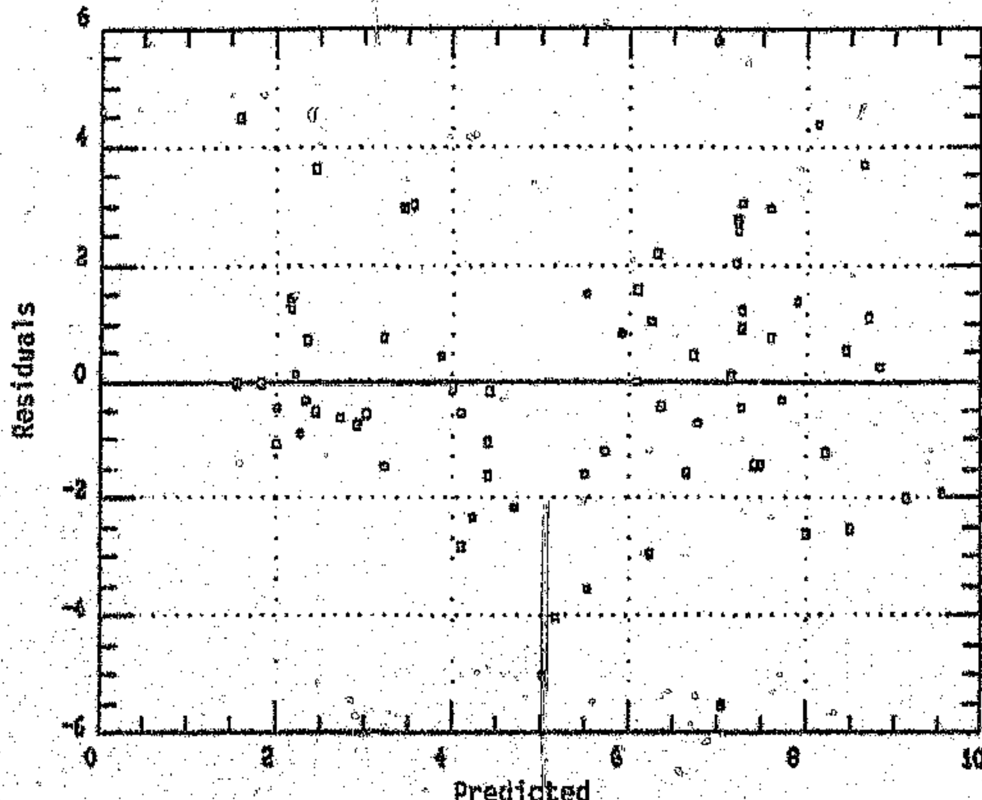
Model fitting results for grass pollen in Pretoria

Independent variable	coefficient	std. error	t-value	sig.level
CONSTANT	2.402838	0.945517	2.5413	0.0133
MPTA.Wndsp14	-0.938532	0.290762	-3.2282	0.0019
MPTA.MinT	0.410533	0.050082	8.1972	0.0000

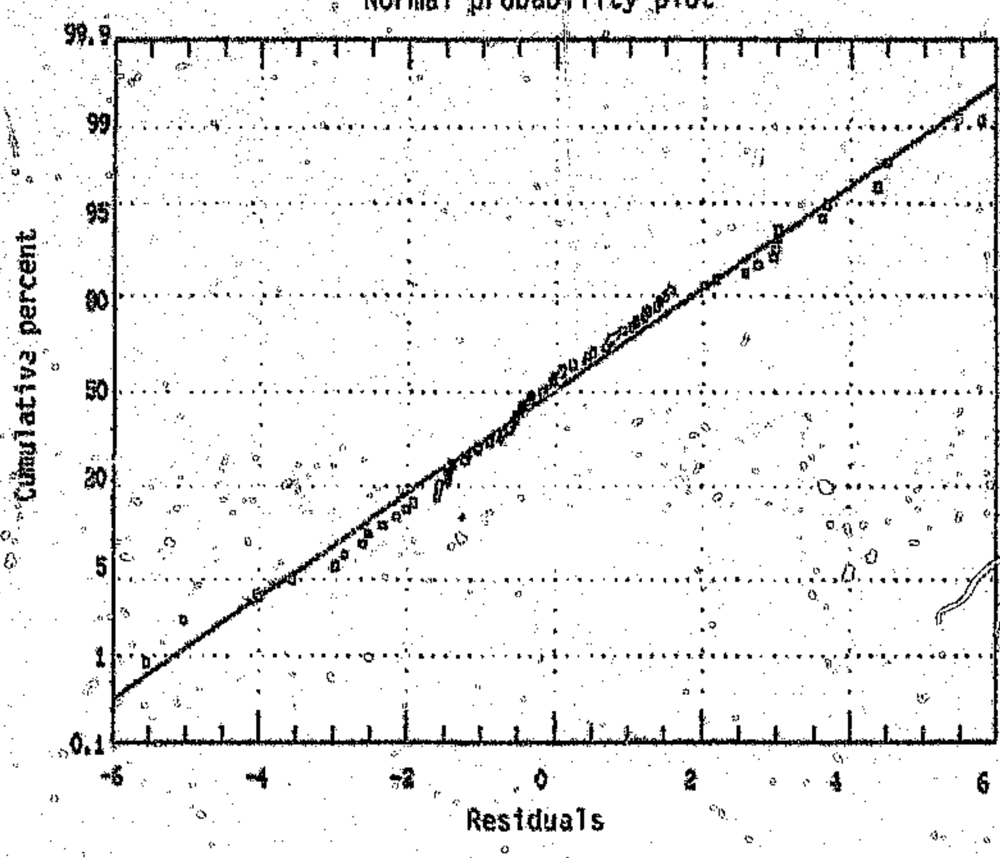
R-SQ. (ADJ.) = 0.5126   SE = 2.198195   MAE= 1.655042   DurbWat= 1.097
Previously: 0.5126   2.198195   1.655042   1.087
72 observations fitted, forecast(s) computed for 0 missing val. of dep. var.


Plot of grass pollen in Pretoria.
Observed
Predicted
0
3
6
9
12
15
0
3
6
9
12
15

Residual plot of grass pollen in Pretoria



Normal probability plot



Appendix 3b Regression of spores on meteorological variables in Pretoria, 1987-1988.

Stepwise selection for spores in Pretoria
(where seas = seasonal indicator)

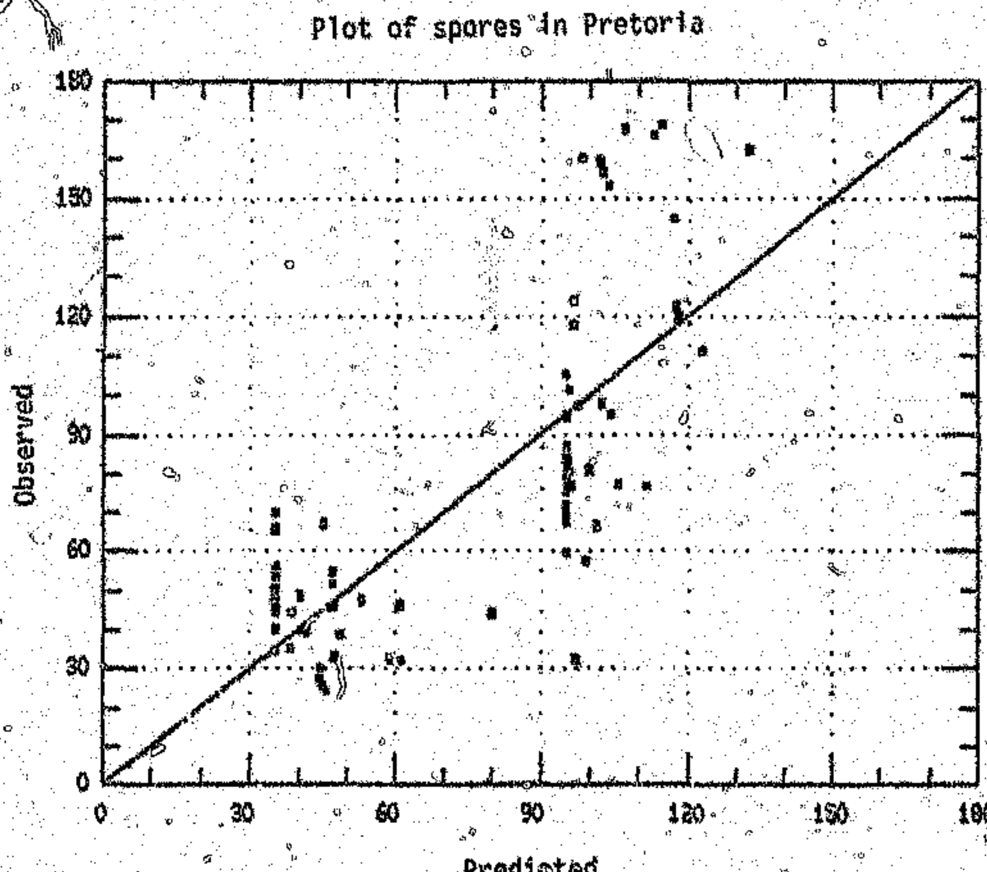
Selection: Forward Maximum steps: 500 F-to-enter: 4.00
Control: Automatic Step: 2 F-to-remove: 4.00
R-squared: .57079 Adjusted: .55835 MSE: 721.916 d.f.: 69

Variables in Model	Coeff.	F-Remove	Variables Not in Model	P.Corr.	F-Enter
12. MPTA.Rain	0.45927	9.1037	4. MPTA.rhat8	.0220	.0330
16. A:INDP.seas	59.9457	87.5357	6. MPTA.rhat20	.0447	.1364
			5. MPTA.rhat14	.0907	.5637
			15. MPTA.Sunhrs	.1104	.8099
			9. MPTA.Wndsp20	.1133	.8845
			7. MPTA.Wndsp8	.1312	1.1909
			14. MPTA.Rdndffs	.1393	1.3466
			3. MPTA.Pat20	.1632	1.8614
			1. A:MPTA.Pat8	.1715	2.0594
			13. MPTA.Rdnglbl	.1731	2.0997
			2. MPTA.Pat14	.1835	2.3706
			11. MPTA.MinT	.1891	2.5204

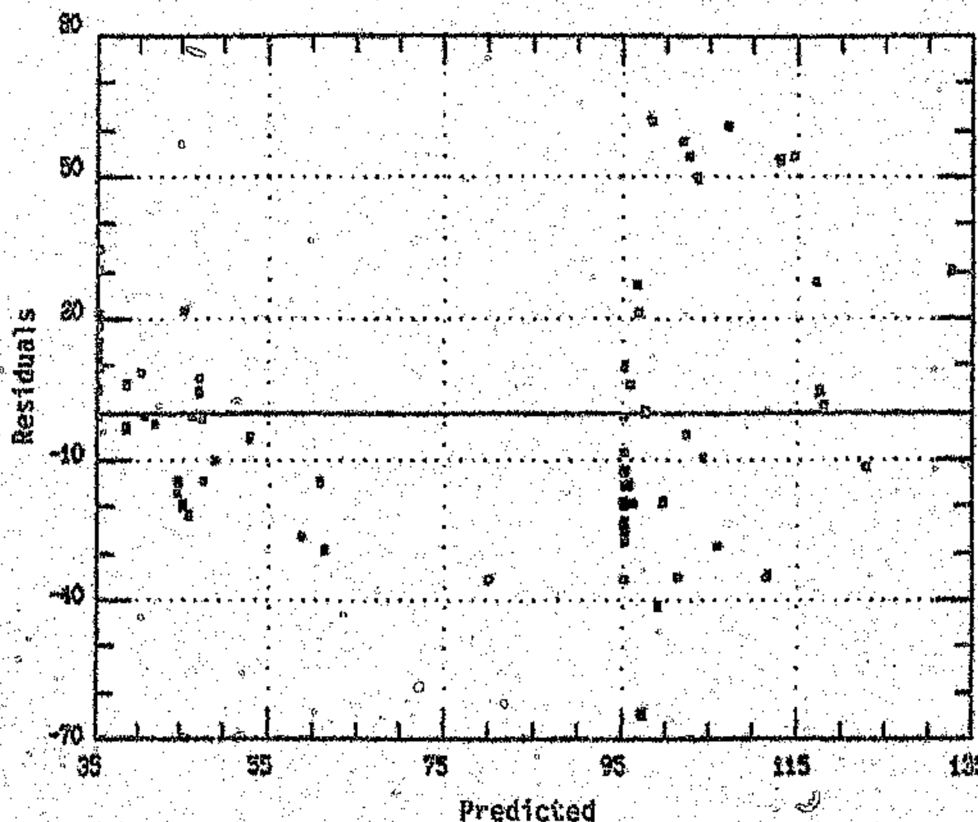
Model fitting results for spores in Pretoria

Independent variable	coefficient	std. error	t-value	sig.level
CONSTANT	35.241888	5.584578	6.3106	0.0000
MPTA.Rain	0.459269	0.152215	3.0172	0.0036
A:INDP.seas	59.945699	6.407157	9.3561	0.0000

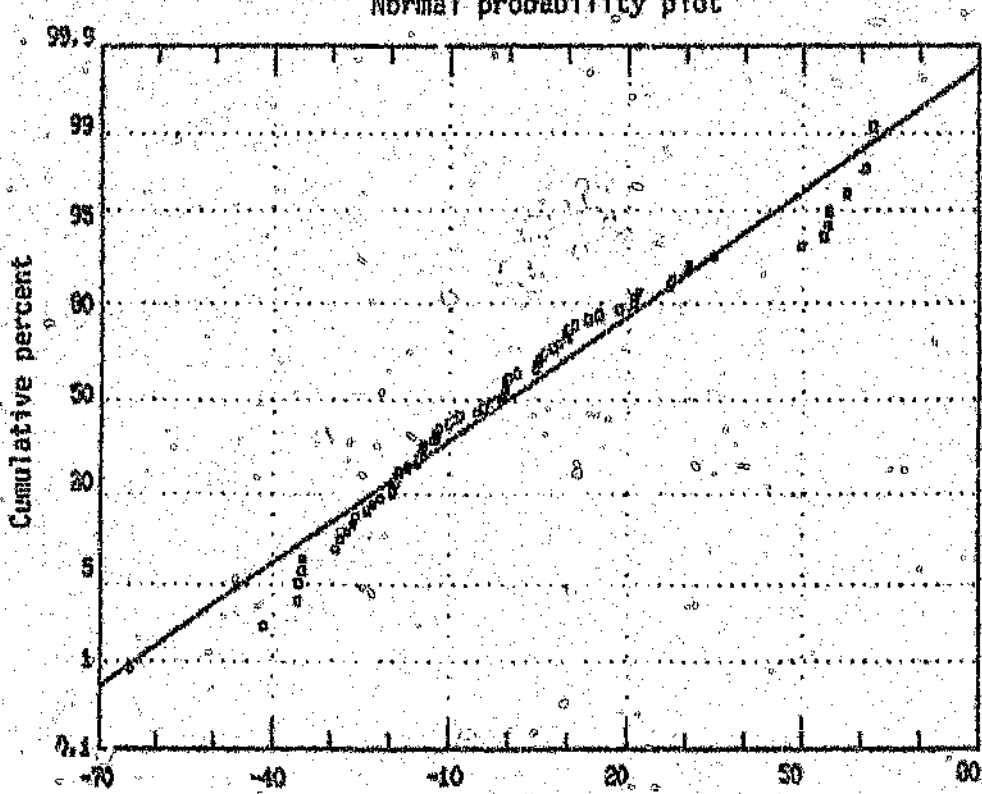
R-SQ. (ADJ.) = 0.5584 SE= 26.868502 MAE= 20.468218 DurbWat= 1.431
Previously: 0.4603 5770.011172 4198.060010 1.424
72 observations fitted, forecast(S) computed for 0 missing val. of dep. var.


Plot of spores in Pretoria
Observed
Predicted
0
30
60
90
120
150
180

Residual plot of spores in Pretoria



Normal probability plot



Appendix 3c Regression of grass pollen on meteorological variables in Johannesburg, 1987-1988.

Stepwise selection for grass pollen in Johannesburg
(where testgrs = seasonal indicator)

Selection: Forward | Maximum steps: 500 | F-to-enter: 4.00
Control: Automatic | Step: 5 | F-to-remove: 4.00

R-squared: .48848 | Adjusted: .46591 | MSE: 5.11586 | d.f.: 68

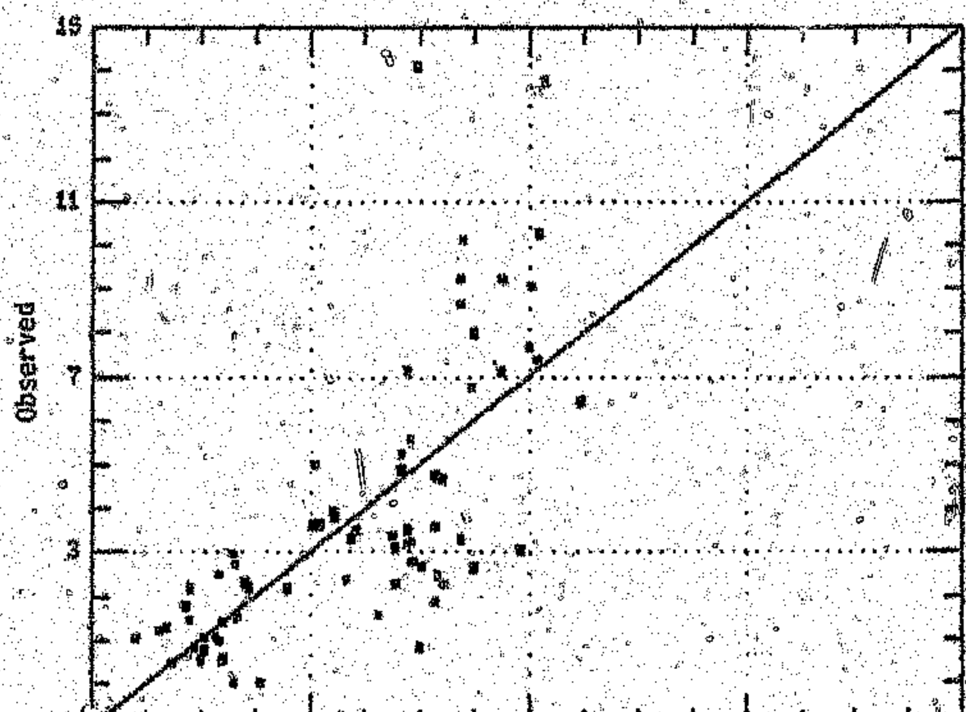
Variables in Model	Coeff.	F-Remove	Variables Not in Model	Corr.	F-Enter
12. MJS.Rain	0.04903	15.9556	4. MJS.rhat8	.0464	.1446
15. MJS.Sunhrs	0.66270	10.1281	1. A:MJS.Pat8	.0521	.1825
16. A:INDJS.testgrs	3.31751	30.9607	2. MJS.Pat14	.1055	.7544
			3. MJS.Pat20	.1396	1.3311
			6. MJS.rhat20	.1425	1.3896
			7. MJS.Wndsp8	.1705	2.0060
			8. MJS.Wndsp14	.1806	2.2585
			13. MJS.Rdnglbf	.1927	2.5830
			10. MJS.MaxT	.1937	2.6122
			14. MJS.Rdndffs	.1970	2.7061
			11. MJS.MinT	.1978	2.7289
			5. MJS.rhat14	.2031	2.8821

Model fitting results for grass pollen in Johannesburg

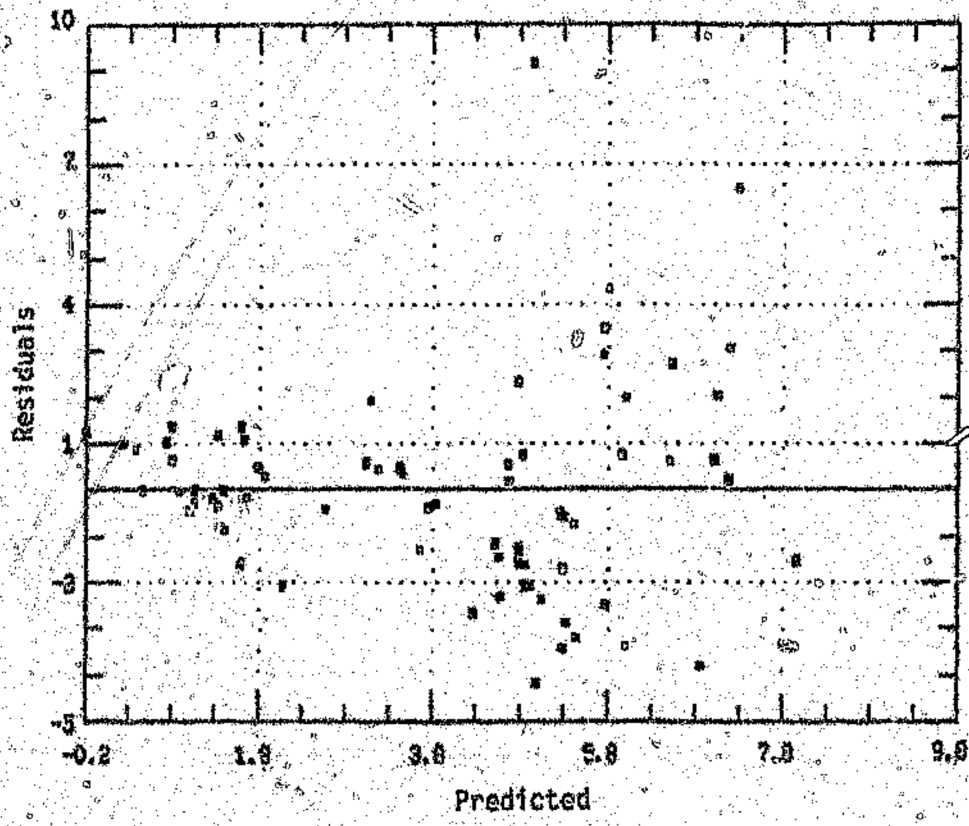
Independent variable	coefficient	std. error	t-value	sig.level
CONSTANT	-5.031511	1.969193	-2.5551	0.0129
MJS.Rain	0.049029	0.012274	3.9945	0.0002
MJS.Sunhrs	0.662697	0.208258	3.1817	0.0022
A:INDJS.testgrs	3.317506	0.596181	5.5646	0.0000

R-SQ. (ADJ.) = 0.4659 SE= 2.261828 MAE= 1.572447 DurbWat= 1.635
Previously: 0.4254 2.345960 1.723693 1.454
72 observations fitted, forecast(S) computed for 0 missing val. of dep. var.

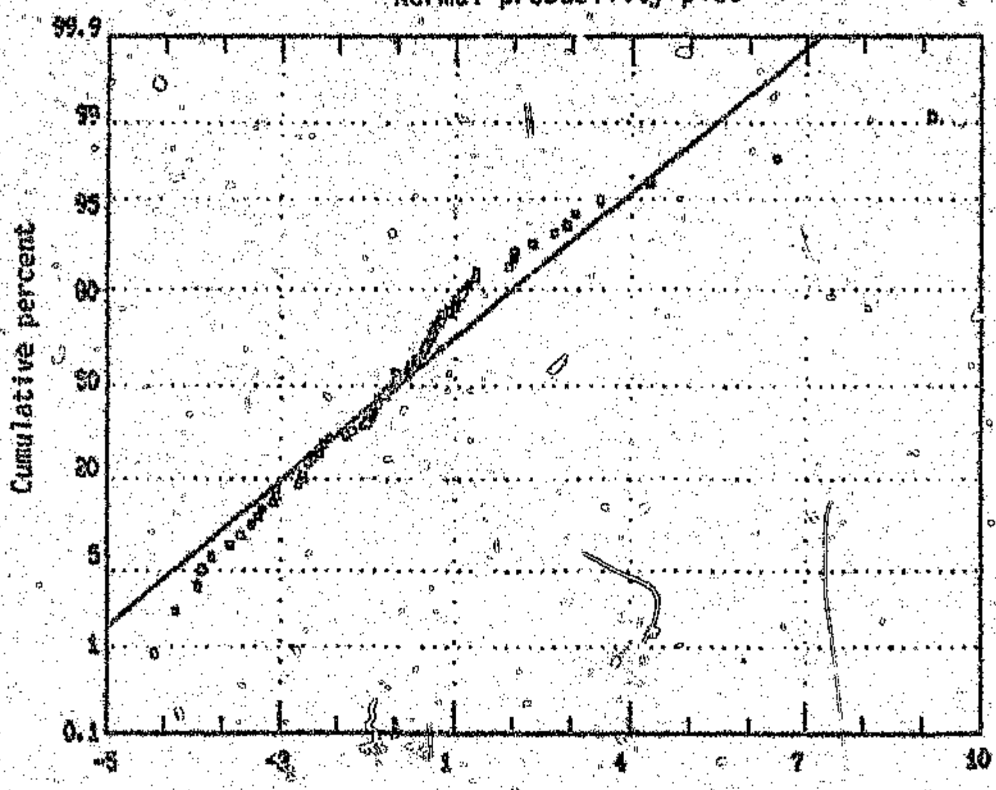
Plot of grass pollen in Johannesburg



Residual plot of grass pollen in Johannesburg



Normal probability plot



Appendix 3d Regression of spores on meteorological variables in Johannesburg, 1987-1988.

Stepwise selection for spores in Johannesburg
(where seas = seasonal indicator)

Selection: Forward   Maximum steps: 500   F-to-enter: 4.00
Control: Automatic   Step: 3   F-to-remove: 4.00
R-squared: .79578   Adjusted: .78677   MSE: 114.184   d.f.: 68

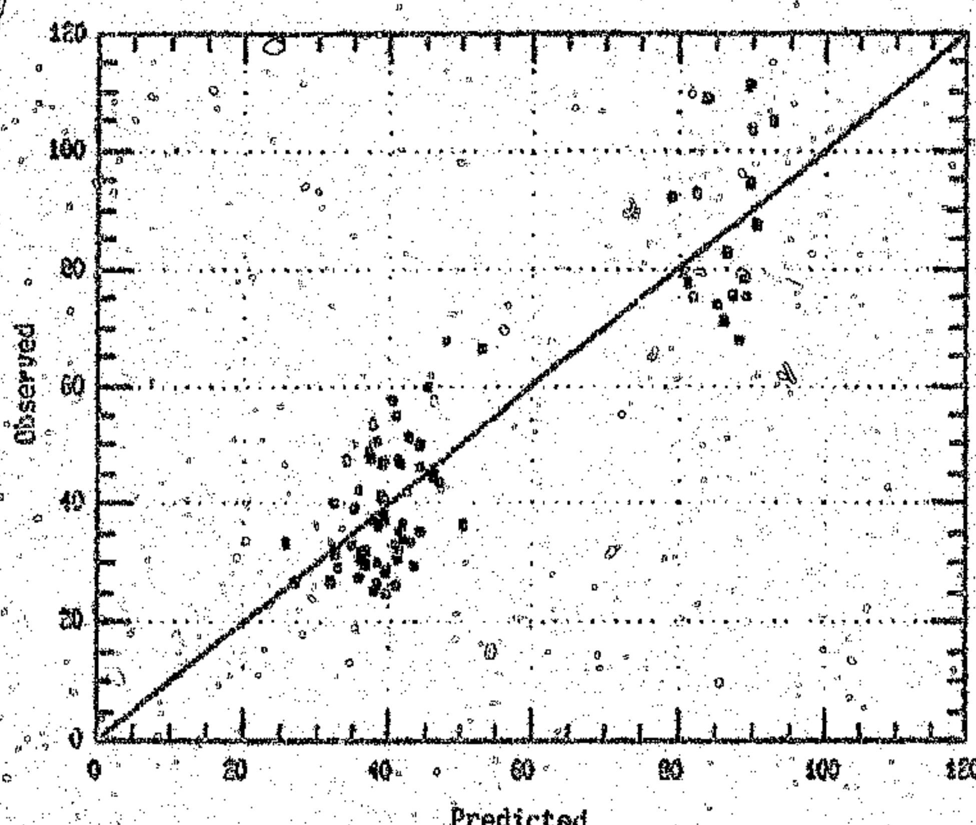
Variables in Model	Coeff.	F-Remove	Variables Not in Model	P.Corr.	F-Enter
3. MJS.Pat20	-1.44740	5.7275	1. MJS.Pat8	.0183	.0223
9. MJS.Wndsp20	-3.94610	12.1463	10. MJS.MinT	.0220	.0325
16. JSPS.seas	42.1124	170.8619	2. MJS.Pat14	.0253	.0428
			13. MJS.Rdnglbl	.0763	.3924
			6. MJS.rhat20	.1027	.7144
			11. MJS.MaxT	.1097	.8168
			12. MJS.Rain	.1168	.9262
			4. MJS.rhat8	.1292	1.1348
			15. MJS.Sunhrs	.1323	1.1930
			8. MJS.Wndsp14	.1332	1.2097
			5. MJS.rhat14	.1332	1.2099
			7. MJS.Wndsp8	.1533	1.6129

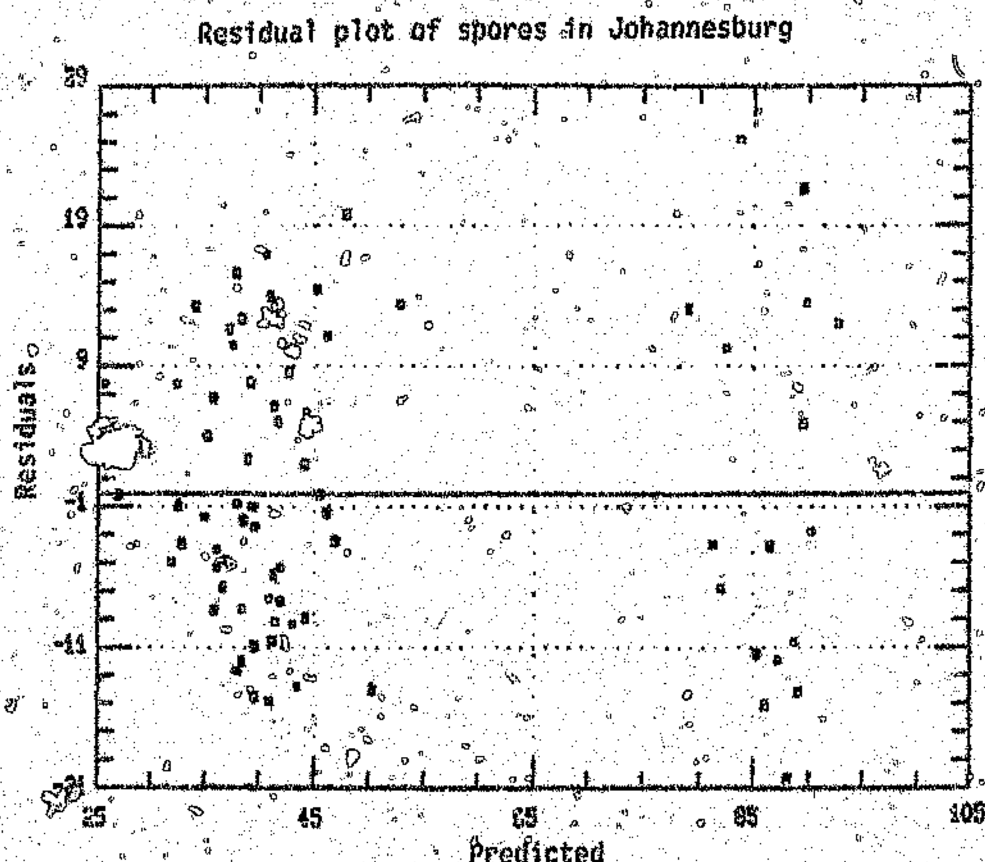
Model fitting results for spores in Johannesburg

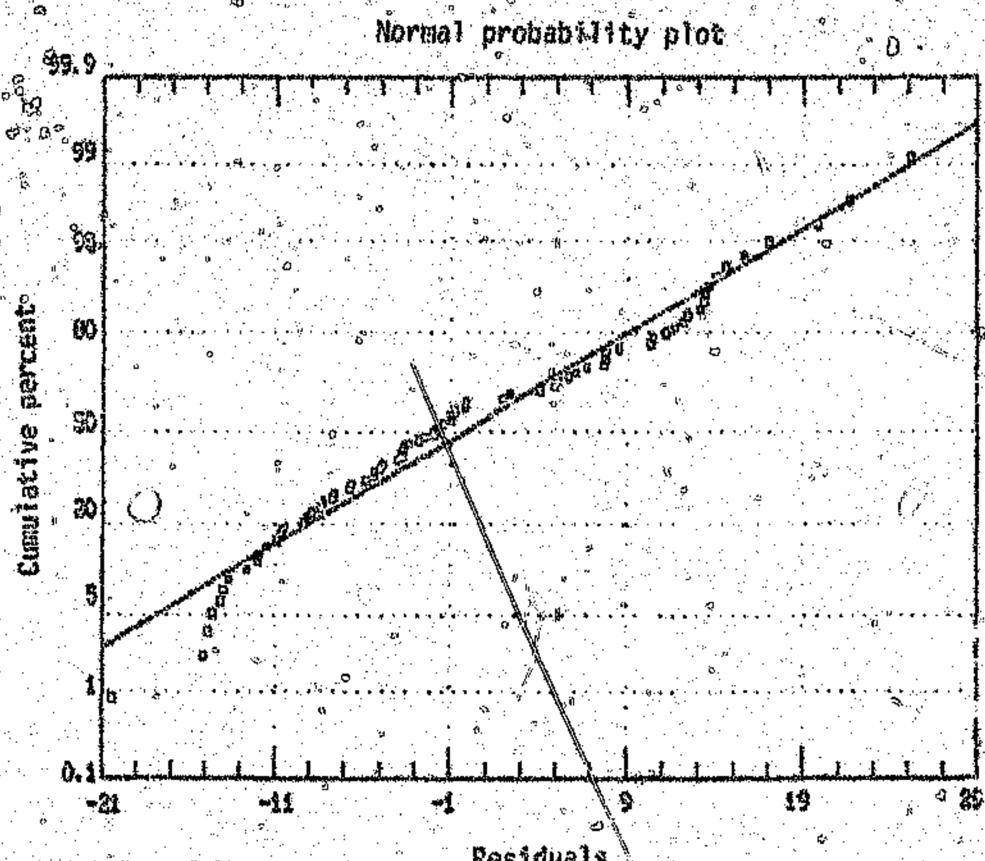
Independent variable	coefficient	std. error	t-value	sig level
CONSTANT	1213.53411	505.722256	2.3996	0.0192
MJS.Pat20	-1.447396	0.60479	-2.3932	0.0195
MJS.Wndsp20	-3.946105	1.132262	-3.4852	0.0009
JSPS.seas	42.112373	3.221715	13.0714	0.0000

R-SQ. (ADJ.) = 0.7868   SE= 10.685679   MAE= 8.826908   DurbWat= 1.381
Previously: 0.0000   0.000000   0.000000   0.000
72 observations fitted, forecast(S) computed for 0 missing val. of dep. var.

Plot of spores in Johannesburg




Residual plot of spores in Johannesburg
29
19
9
-1
-11
-21
25
45
65
85
105
Residuals
Predicted


Normal probability plot
99.9
99
95
80
50
20
5
1
0.1
-21
-11
-1
9
19
25
Cumulative percent
Residuals

Appendix 4 Correlation coefficients of meteorological factors at Johannesburg and Pretoria, 1987-1988:

Maximum temperature	0.97
Minimum temperature	0.97
Rainfall	0.75
Pressure at 8h00	0.13
Pressure at 14h00	0.19
Pressure at 20h00	0.22
Relative humidity at 8h00	0.82
Relative humidity at 14h00	0.96
Relative humidity at 20h00	0.91
Windspeed at 8h00	0.66
Windspeed at 14h00	0.58
Windspeed at 20h00	0.53
Sunhours	0.93
Radiation, global	1.00
Radiation, diffuse	1.00

Appendix 5 Correlation coefficients of meteorological at Pretoria, 1987-1988.

		1	2	3	4	5	6	7	8
1	Maximum temperature	1.00	0.93	0.32	-0.06	-0.16	-0.16	0.05	0.29
2	Minimum temperature	0.93	1.00	0.48	-0.11	-0.21	-0.20	0.28	0.57
3	Rainfall	0.32	0.48	1.00	-0.04	-0.09	-0.08	0.42	0.64
4	Pressure at 8h00	-0.06	-0.11	-0.04	1.00	0.91	0.90	0.19	0.09
5	Pressure at 14h00	-0.16	-0.21	-0.09	0.91	1.00	0.99	0.14	0.03
6	Pressure at 20h00	-0.16	-0.20	-0.08	0.90	0.99	1.00	0.15	0.04
7	Relative humidity at 8h00	0.05	0.28	0.42	0.19	0.14	0.15	1.00	0.81
8	Relative humidity at 14h00	0.29	0.57	0.64	0.09	0.03	0.04	0.81	1.00
9	Relative humidity at 20h00	0.26	0.50	0.67	0.10	0.07	0.08	0.80	0.91
10	Windspeed at 8h00	0.39	0.52	0.38	0.18	0.12	0.13	0.19	0.48
11	Windspeed at 14h00	-0.06	0.02	0.13	0.30	0.30	0.31	0.06	0.17
12	Windspeed at 20h00	0.15	0.25	0.33	0.51	0.12	0.13	-0.03	0.21
13	Sunhours	0.05	-0.24	-0.50	-0.10	-0.07	-0.07	-0.64	-0.79
14	Radiation, global	0.82	0.75	0.19	-0.22	-0.30	-0.30	-0.18	0.10
15	Radiation, diffuse	0.66	0.82	0.51	0.06	-0.02	-0.01	0.44	0.75

Appendix 5 Correlation coefficients cf meteorological at Pretoria, 1987-1988 (continued).

		9	10	11	12	13	14	15
1	Maximum temperature	0.25	0.39	-0.06	0.15	0.05	0.82	0.66
2	Minimum temperature	0.50	0.52	0.02	0.25	-0.24	0.75	0.82
3	Rainfall	0.67	0.36	0.13	0.33	-0.50	0.19	0.51
4	Pressure at 8h00	0.10	0.18	0.30	0.15	-0.10	-0.22	0.06
5	Pressure at 14h00	0.07	0.12	0.30	0.12	-0.07	-0.30	-0.02
6	Pressure at 20h00	0.08	0.13	0.31	0.13	-0.07	-0.30	-0.01
7	Relative humidity at 8h00	0.80	0.19	0.06	-0.03	-0.64	-0.18	0.44
8	Relative humidity at 14h00	0.91	0.48	0.17	0.21	-0.79	0.10	0.75
9	Relative humidity at 20h00	1.00	0.34	0.06	0.17	-0.74	0.04	0.68
10	Windspeed at 8h00	0.34	1.00	0.61	0.67	-0.29	0.39	0.58
11	Windspeed at 14h00	0.06	0.61	1.00	0.63	-0.15	0.01	0.10
12	Windspeed at 20h00	0.17	0.67	0.63	1.00	-0.18	0.24	0.32
13	Sunhours	-0.74	-0.29	-0.15	-0.18	1.00	0.28	-0.54
14	Radiation, global	0.04	0.39	0.01	0.24	0.28	1.00	0.57
15	Radiation, diffuse	0.68	0.58	0.10	0.32	-0.54	0.57	1.00

Appendix 6 Cross-correlation analysis of airspora and meteorological factors

(each Lag = 10 days, so that

Lag 0 = present time

Lag 1 = 10 days hence

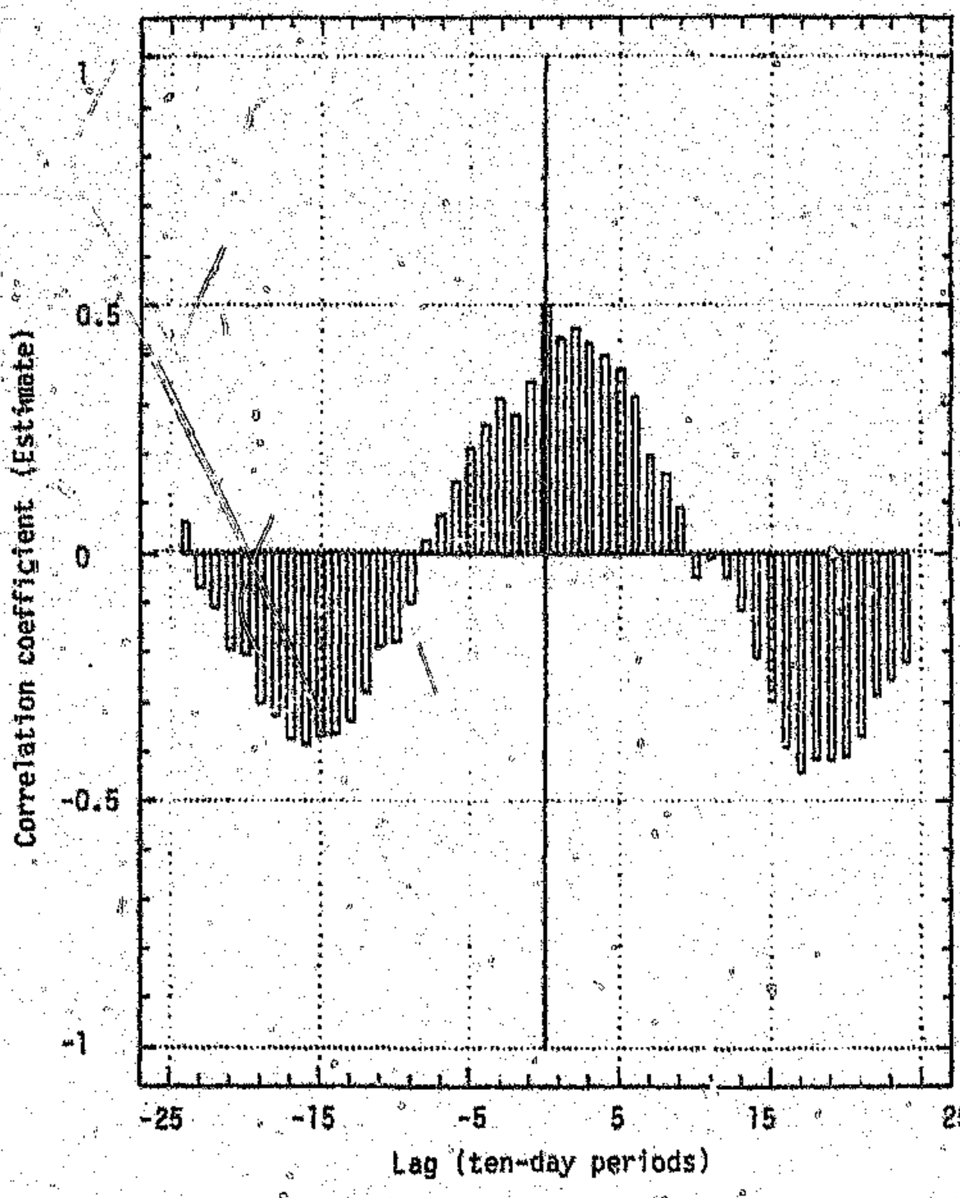
Lag -1 = 10 days ago, etc,

and where Estimate = correlation coefficient of the airspora with meteorological factor at specified Lag;

a plot of the numerical data is shown below each table of correlation coefficients).

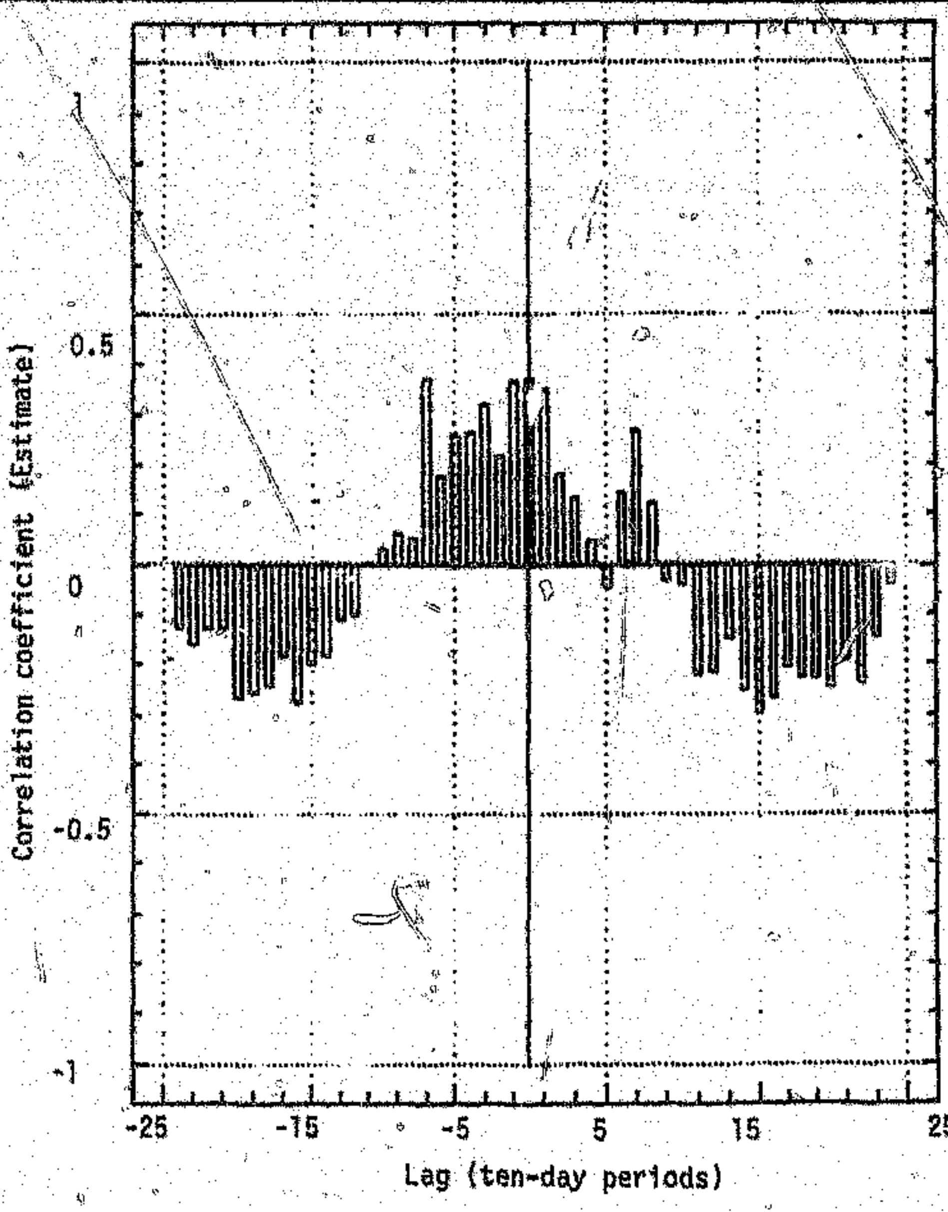
Appendix 6a **Grass pollen and maximum temperature in Johannesburg, 1987-1988.**

Lag	Estimate	Lag	Estimate	Lag	Estimate	Lag	Estimate
-24	.05892	-23	-.06826	-22	-.11251	-21	-.19316
-20	-.20515	-19	-.30074	-18	-.32987	-17	-.37520
-16	-.38288	-15	-.36897	-14	-.36520	-13	-.33688
-12	-.27937	-11	-.10905	-10	-.17621	-9	-.10017
-8	.02281	-7	.07414	-6	.14471	-5	.21160
-4	.25710	-3	.30672	-2	.27523	-1	.34627
0	.49843	1	.43130	2	.45446	3	.42418
4	.39719	5	.37250	6	.31204	7	.19399
8	.15597	9	.09237	10	-.04696	11	-.01045
12	-.04986	13	-.11460	14	-.20982	15	-.29536
16	-.39086	17	-.44113	18	-.41441	19	-.41496
20	-.41032	21	-.37174	22	-.28881	23	-.25589
24	-.22117						



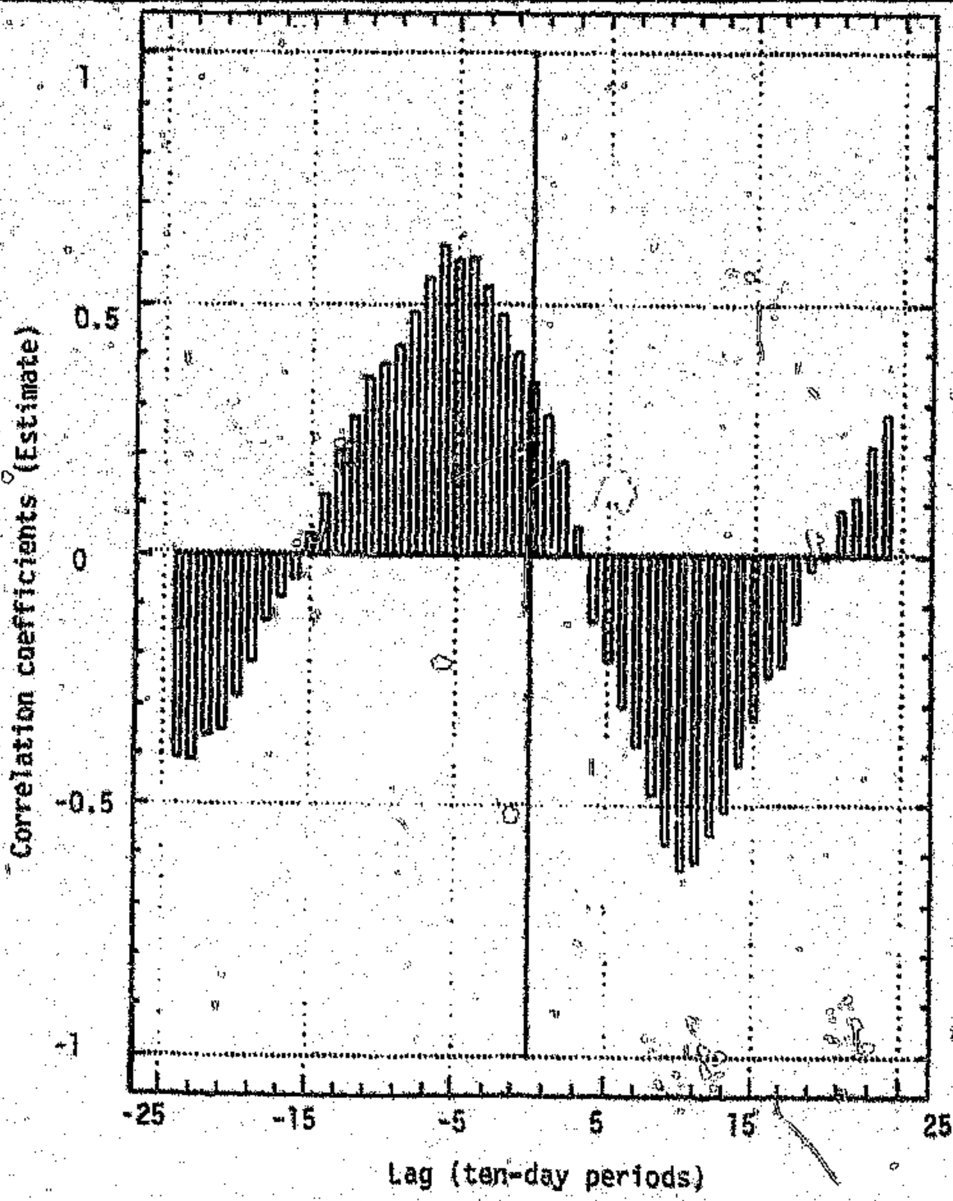
Appendix 6b **Grass pollen and rain in Johannesburg, 1987-1988.**

Lag	Estimate	Lag	Estimate	Lag	Estimate	Lag	Estimate
-24	-.12488	-23	-.15873	-22	-.12460	-21	-.12753
-20	-.26572	-19	-.25662	-18	-.23942	-17	-.18580
-16	-.27791	-15	-.19682	-14	-.18464	-13	-.11029
-12	-.10167	-11	.00078	-10	.03050	-9	.06202
-8	.04938	-7	.37015	-6	.174[illegible]3	-5	.25836
-4	.26174	-3	.31602	-2	.21407	-1	.36233
0	.37077	1	.35008	2	.18069	3	.13084
4	.04662	5	-.04405	6	.13213	7	.26518
8	.11965	9	-.03538	10	-.03798	11	-.22061
12	-.21480	13	-.14651	14	-.25152	15	-.29796
16	-.26754	17	-.20323	18	-.22709	19	-.22443
20	-.24700	21	-.18763	22	-.23420	23	-.14324
24	-.03876						



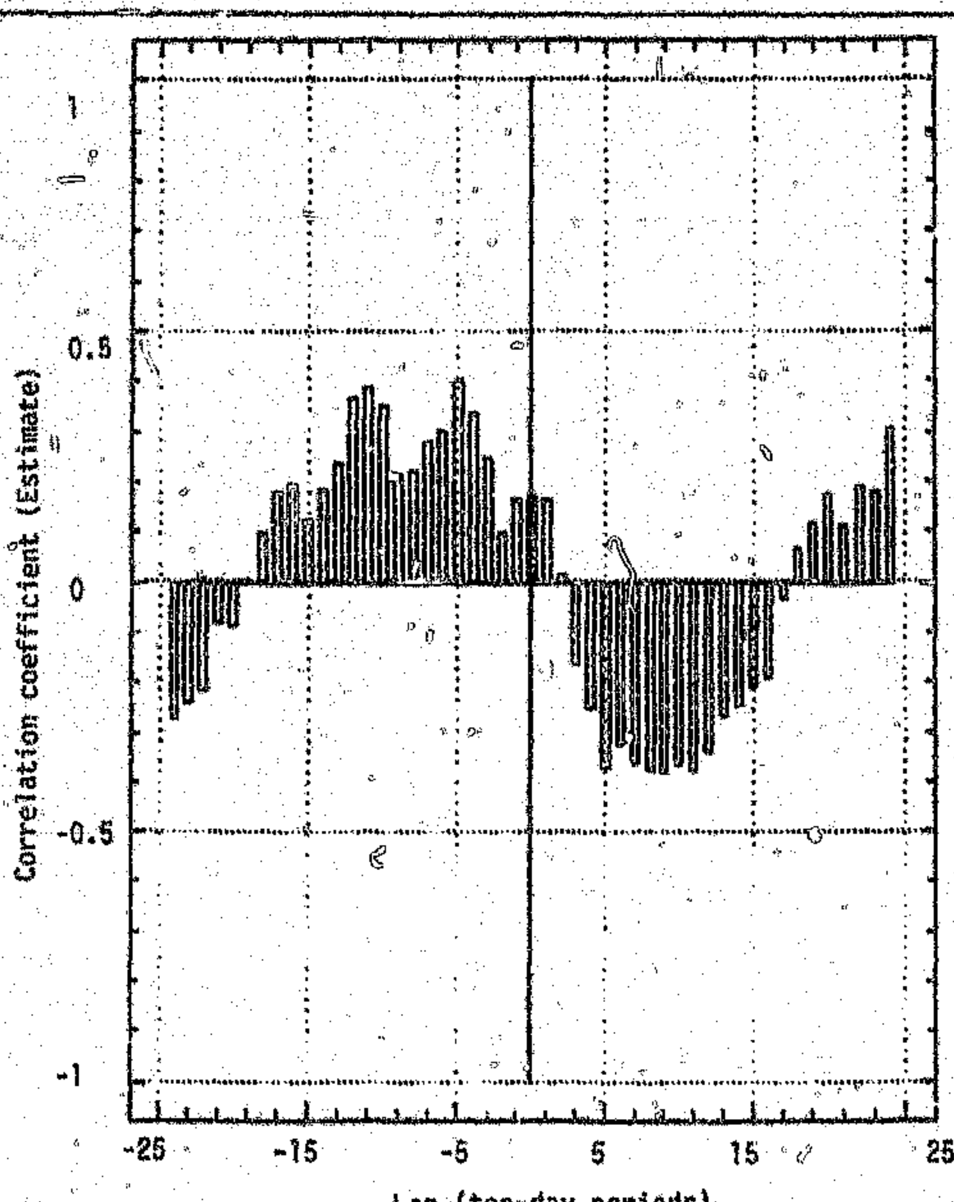
Appendix 6c **Spores and maximum temperature in Johannesburg, 1987-1988.**

Lag	Estimate	Lag	Estimate	Lag	Estimate	Lag	Estimate
-24	-.40596	-23	-.40963	-22	-.35935	-21	-.34972
-20	-.28415	-19	-.21511	-18	-.13999	-17	-.08698
-16	-.04958	-15	.04110	-14	.11848	-13	.20480
-12	.27311	-11	.35429	-10	.38203	-9	.41882
-8	.48160	-7	.55178	-6	.61698	-5	.58601
-4	.59237	-3	.52804	-2	.47813	-1	.39937
0	.34188	1	.27942	2	.18234	3	.05324
4	-.13017	5	-.20813	6	-.30425	7	-.38147
8	-.47789	9	-.57831	10	-.62853	11	-.61160
12	-.55637	13	-.50946	14	-.41476	15	-.32877
16	-.24115	17	-.21985	18	-.13058	19	-.02786
20	-.00737	21	.08457	22	.11098	23	.21355
24	.27604						



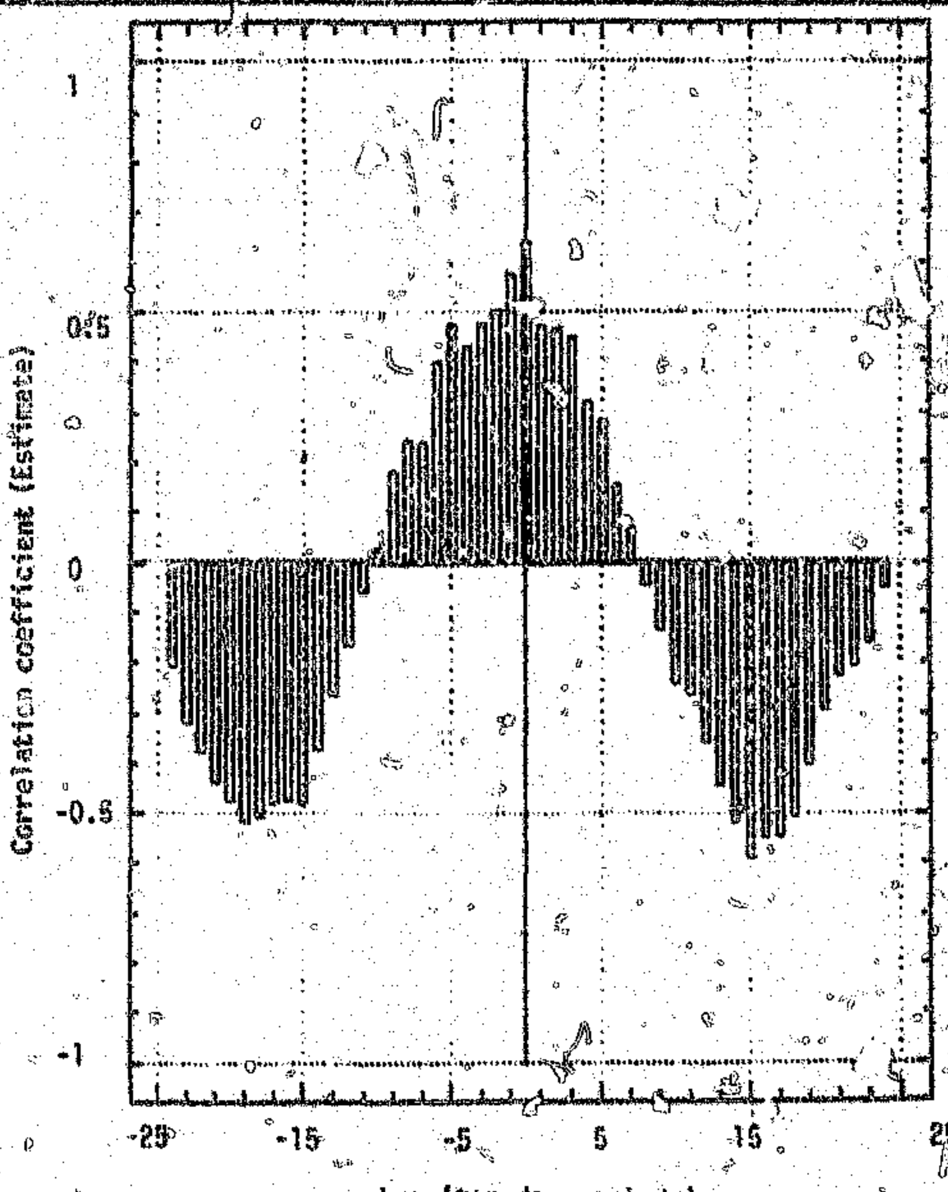
Appendix 6d Spores and rain in Johannesburg, 1987-1988.

Lag	Estimate	Lag	Estimate	Lag	Estimate	Lag	Estimate
-24	-.26896	-23	-.23795	-22	-.21426	-21	-.08032
-20	-.08281	-19	.00473	-18	.09428	-17	.17999
-16	.19226	-15	.12393	-14	.18413	-13	.23292
-12	.36542	-11	.38382	-10	.35063	-9	.20992
-8	.22150	-7	.27496	-6	.29810	-5	.40342
-4	.33349	-3	.24615	-2	.09765	-1	.16378
0	.17044	1	.16473	2	.01222	3	-.16377
4	-.24995	5	-.36979	6	-.32317	7	-.36102
8	-.37737	9	-.37964	10	-.36638	11	-.37336
12	-.33775	13	-.26874	14	-.24434	15	-.20729
16	-.18960	17	-.03231	18	.06543	19	.11589
20	.17528	21	.10997	22	.18647	23	.17637
24	.30193						



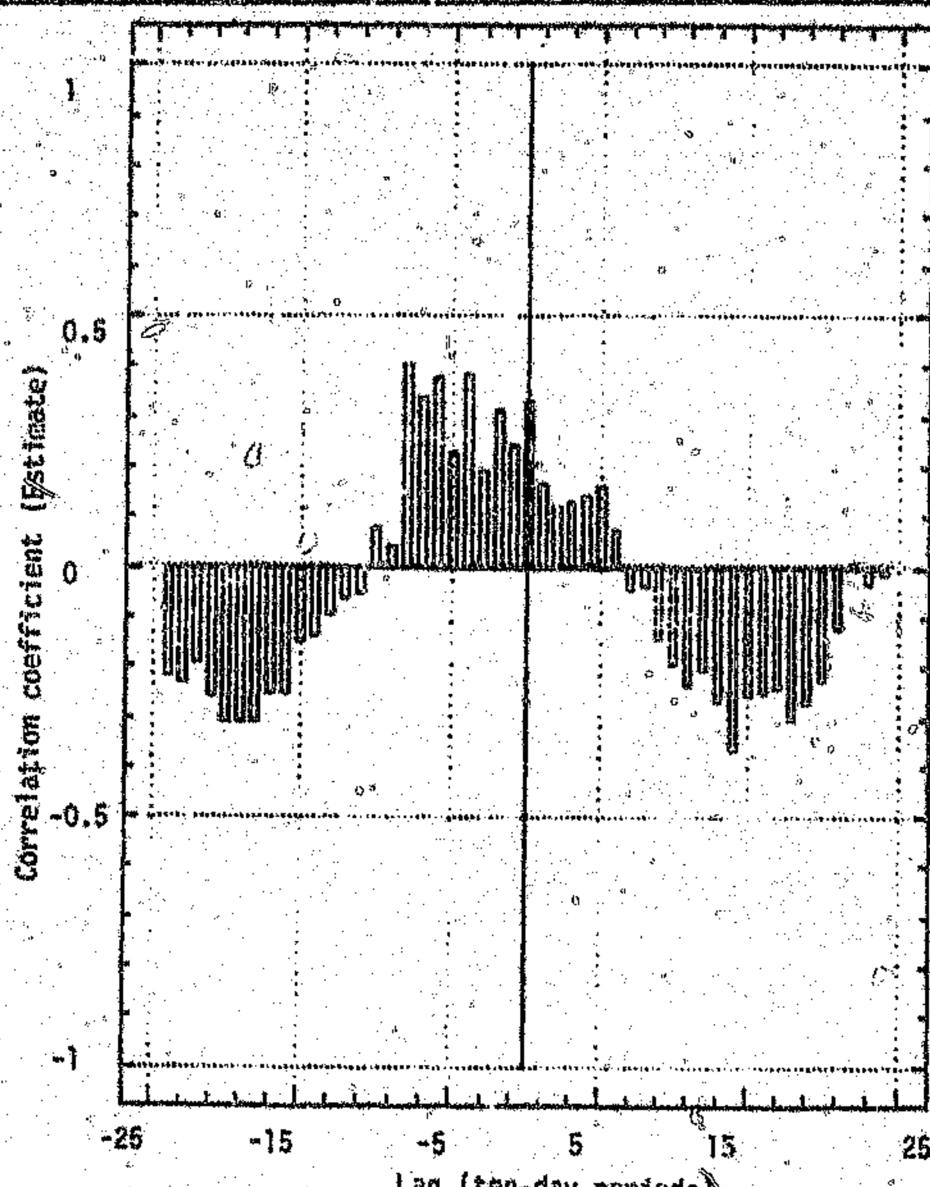
Appendix 6c Grass pollen and maximum temperature in Pretoria, 1987-1988.

Lag	Estimate	Lag	Estimate	Lag	Estimate	Lag	Estimate
-24	-.20167	-23	-.31951	-22	-.37748	-21	-.43902
-20	-.47562	-19	-.51238	-18	-.50427	-17	-.47932
-16	-.47252	-15	-.48078	-14	-.37190	-13	-.26068
-12	-.16150	-11	-.05701	-10	.02469	9	.17875
-8	.23879	-7	.23590	-6	.39720	-5	.47287
-4	.42432	3	.47603	-2	.49755	-1	.57255
0	.63886	1	.46756	2	.46507	3	.44608
4	.31674	5	.28070	6	.15071	7	.06590
8	-.04217	9	-.13143	10	-.24147	11	-.26182
12	-.35477	13	-.44300	14	-.51332	15	-.58061
16	-.54527	17	-.54473	18	-.50175	19	-.39909
20	-.29401	21	-.22665	22	-.20486	23	-.15651
24	-.04834						



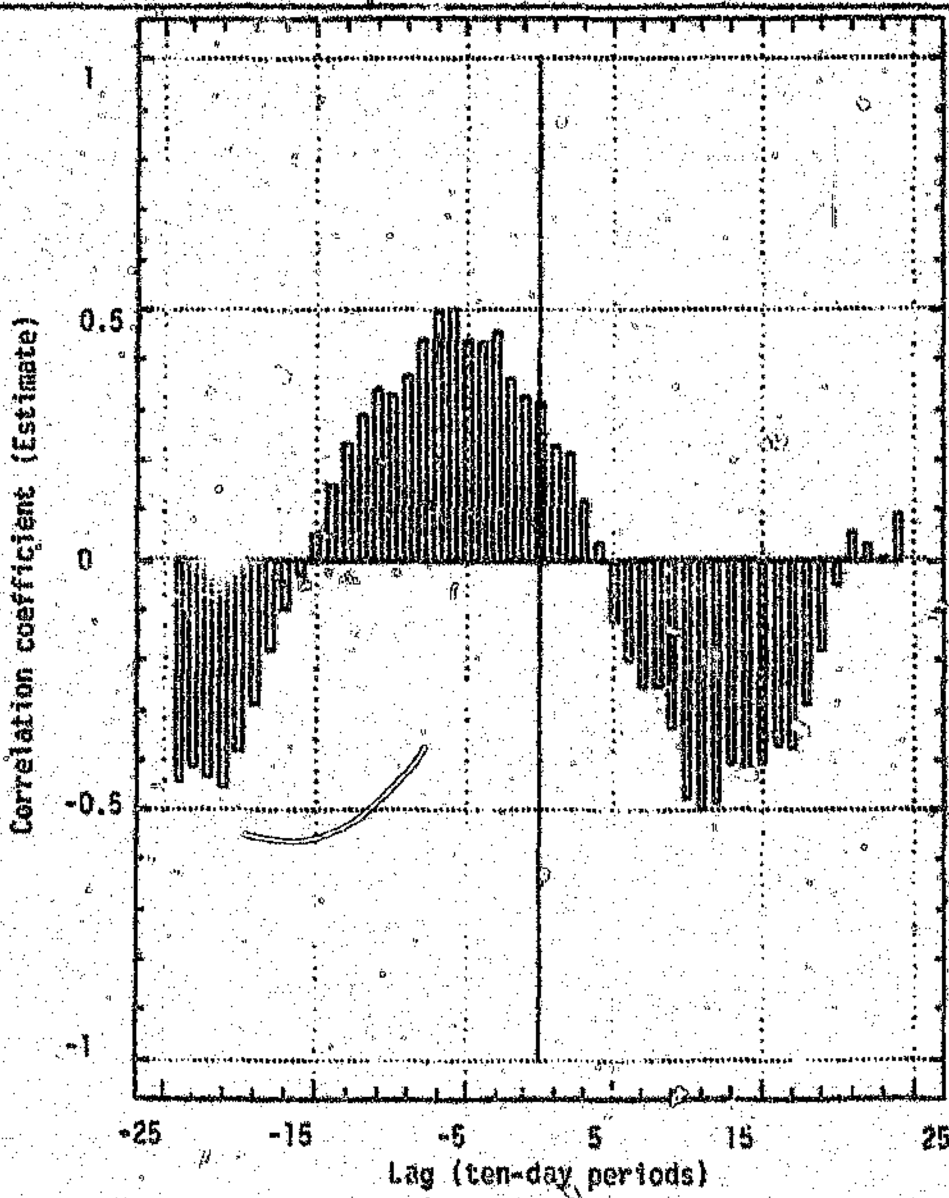
Appendix 6f Grass pollen and rain in Pretoria, 1987-1988.

Lag	Estimate	Lag	Estimate	Lag	Estimate	Lag	Estimate
-24	-.21588	-23	-.22168	-22	-.18619	-21	-.25591
-20	-.30658	-19	-.30748	-18	-.30892	-17	-.25219
-16	-.25110	-15	-.14815	-14	-.13591	-13	-.09622
-12	-.06519	-11	-.05399	-10	.07377	-9	.03880
-8	.39876	-7	.33595	-6	.37680	-5	.22386
-4	.37844	-3	.19110	-2	.30602	-1	.23975
0	.32782	1	.16148	2	.11714	3	.12888
4	.13913	5	.15979	6	.06809	7	-.04223
8	-.03937	9	-.14125	10	-.19628	11	-.23445
12	-.20561	13	-.26831	14	-.36273	15	-.25639
16	-.25141	17	-.23808	18	-.30209	19	-.26932
20	-.22239	21	-.12290	22	.00674	23	-.03384
24	-.01110						



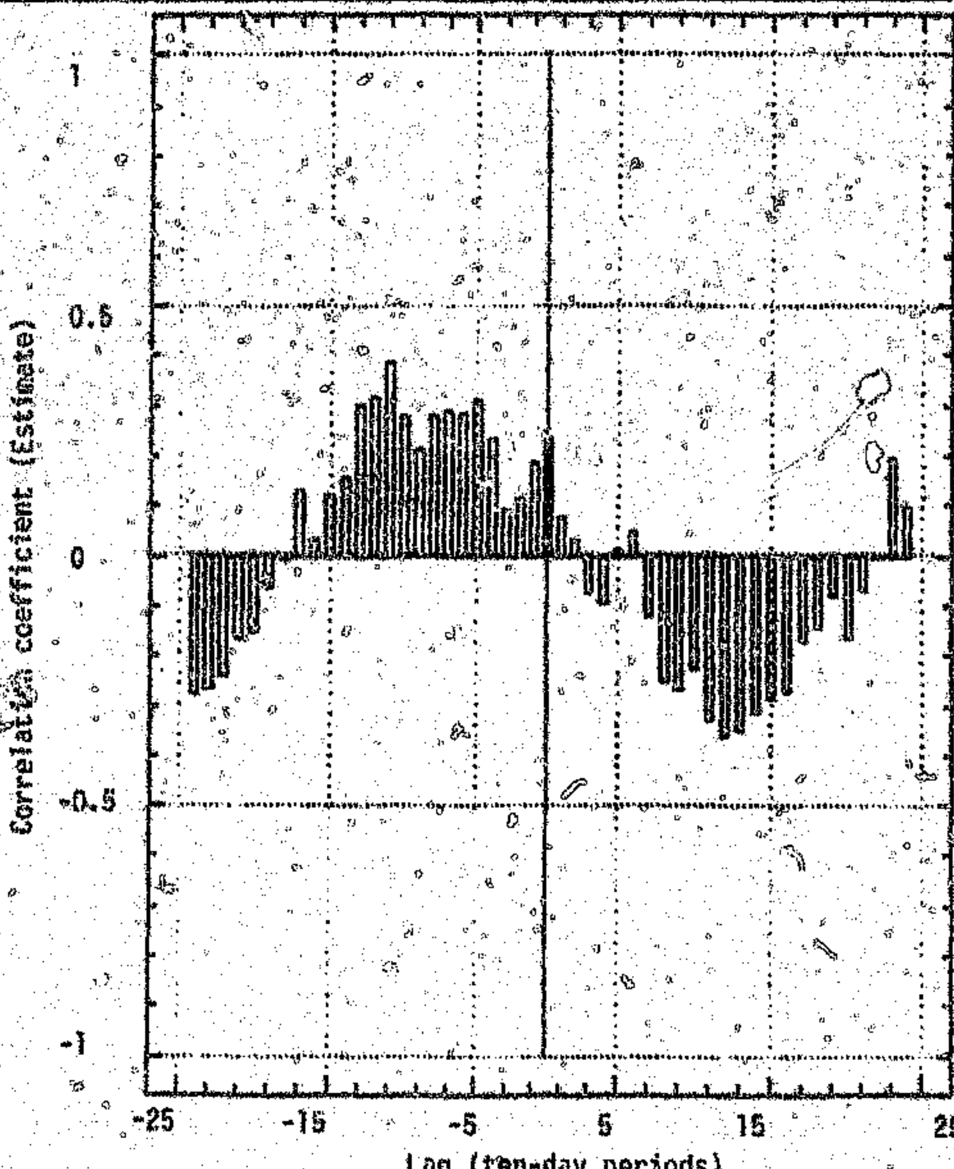
Appendix 6g Spores and maximum temperature in Pretoria, 1987-1988.

Lag	Estimate	Lag	Estimate	Lag	Estimate	Lag	Estimate
-24	-.44198	-23	-.40948	-22	-.43414	-21	-.45244
-20	-.37962	-19	-.28683	-18	-.17956	-17	-.09759
-16	-.02753	-15	.04807	-14	.14829	-13	.23012
-12	.28655	-11	.33971	-10	.33033	-9	.36738
-8	.43562	-7	.49582	-6	.49759	-5	.43869
-4	.43246	-3	.45129	-2	.36003	-1	.32436
0	.31063	1	.22539	2	.20923	3	.11580
4	.03305	5	-.12173	6	-.19806	7	-.25044
8	-.25256	9	-.33352	10	-.47141	11	-.49385
12	-.48257	13	-.40748	14	-.41900	15	-.40417
16	-.37102	17	-.37322	18	-.28921	19	-.17702
20	-.04710	21	.05287	22	.02837	23	.00324
24	.09279						



Appendix 6h Spores and rain in Pretoria, 1987-1988.

Lag	Estimate	Lag	Estimate	Lag	Estimate	Lag	Estimate
-24	-.27714	-23	-.26759	-22	-.23858	-21	-.16027
-20	-.15327	-19	-.06619	-18	-.00817	-17	.12837
-16	.02962	-15	.11861	-14	.15069	-13	.29557
-12	.31361	-11	.38699	-10	.27435	-9	.20910
-8	.27497	-7	.28663	-6	.28337	-5	.30655
-4	.22856	-3	.08997	-2	.11246	-1	.18172
0	.23504	1	.07380	2	.02813	3	-.07712
4	-.09497	5	.00539	6	.04267	7	-.11999
8	-.25066	9	-.26689	10	-.22547	11	-.32968
12	-.36071	13	-.34687	14	-.31116	15	-.28881
16	-.26985	17	-.16926	18	-.13966	19	-.08157
20	-.16208	21	-.06756	22	-.00128	23	.19294
24	.09580						



Appendix 7 CA of sites 3 - 11.

Appendix 7 Site 3.

Input
33 4 0 2
Output
1 1 1 1 1
Columns
A,S,C,V
Template
1111
Graphs
12002 3311
Data

1	795	890	524	55
3	126	0	0	0
4	0	0	0	5
6	13305	15850	14570	68
7	2050	1990	1050	0
8	0	0	0	5
11	126	0	0	0
12	0	0	0	11
13	0	0	0	15
14	293	160	120	21
15	669	450	670	9
19	0	0	0	4
20	628	877	1571	990
21	0	0	0	10
22	335	220	524	11
24	2678	1316	2094	0
25	0	0	0	6
28	167	0	0	6
30	209	0	0	5
32	2427	1754	2618	9
33	1757	1600	970	1069
35	84	0	0	0
36	0	754	670	1
38	795	250	200	750
40	2301	250	300	2
41	84	300	0	1
42	0	877	250	0
44	0	439	50	0
49	167	200	100	15
50	1213	1754	2618	1064
52	126	877	100	70
53	377	439	0	7
55	69289	68752	71102	95791

Inertias and percentages of inertia

```
1  0.081527  68.35%  [[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[
2  0.026427  22.16%  [[[[[[[[[[[[[[[[
3  0.011318   9.49%  [[[[[[[
   ________
   0.119272
```

Appendix 7 Site 3 (continued).

Row Contributions

I	NAME	QLT	MAS	INR	k=1	COR	CTR	k=2	COR	CTR
1	1	898	6	16	543	898	20	2	0	0
2	3	955	0	8	618	127	1	1576	828	30
3	4	990	0	0	-1723	990	0	-0	0	0
4	6	996	109	308	573	977	441	-79	19	26
5	7	870	13	46	605	849	57	96	21	4
6	8	990	0	0	-1723	990	0	-0	0	0
7	11	955	0	8	618	127	1	1576	828	30
8	12	990	0	1	-1723	990	1	-0	0	0
9	13	990	0	1	-1723	990	1	-0	0	0
10	14	948	1	5	514	611	5	381	336	8
11	15	891	4	14	548	836	17	141	55	3
12	19	990	0	0	-1723	990	0	-0	0	0
13	20	246	10	10	-15	2	0	-168	244	11
14	21	990	0	1	-1723	990	1	-0	0	0
15	22	566	3	11	511	561	9	50	5	0
16	24	938	15	55	564	732	59	299	206	52
17	25	990	0	0	-1723	990	1	-0	0	0
18	28	953	0	10	537	105	2	1522	847	38
19	30	954	1	13	563	113	1	1539	841	48
20	32	873	17	52	555	844	64	103	29	7
21	33	457	13	7	139	313	3	95	145	5
22	35	955	0	5	618	127	1	1576	828	20
23	36	993	3	29	570	314	13	-839	680	88
24	38	887	5	13	-273	246	5	441	641	37
25	40	971	7	100	601	216	32	1126	756	342
26	41	469	1	13	669	277	5	-558	192	11
27	42	855	3	38	630	245	14	-994	610	105
28	44	711	1	23	663	194	7	-1082	517	54
29	49	826	1	3	533	824	4	-21	1	0
30	50	497	17	19	182	248	7	-183	249	21
31	52	605	3	33	516	201	10	-732	404	59
32	53	426	2	17	-637	415	10	105	11	1
33	55	999	762	141	-149	999	206	-0	0	0

Column Contributions

J	NAME	QLT	MAS	INR	k=1	COR	CTR	k=2	COR	CTR
1	A	985	250	206	176	317	95	256	668	621
2	S	848	250	184	197	444	120	-188	403	335
3	C	382	250	102	118	287	43	-68	96	44
4	V	999	250	508	-492	999	742	-0	0	0

Appendix 7. Site 4.

Input
23 4 0 2
Output
1 1 1 1 1
Columns
A,S,C,V
Template
1111
Graphs
12002 3311
Data

1	7989	1560	930	5
2	60	0	0	0
6	13476	11980	13960	31
7	2922	2850	3570	220
13	0	0	0	18
20	835	0	0	0
22	179	0	0	0
24	2027	1790	2050	0
30	60	0	0	0
32	2087	1900	1540	990
33	1312	1570	960	2350
36	0	900	0	1
38	537	500	0	10
40	540	980	160	90
41	60	0	0	2
44	60	0	0	0
45	119	0	0	0
46	60	0	0	0
47	60	0	0	0
49	119	500	0	2
50	1312	930	1408	148[illegible]
53	298	0	0	9
55	72090	74490	75362	94602

Inertias and percentages of inertia

```
1  0.065816   72.18%   [[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[
2  0.015127   16.59%   [[[[[[[[[[[
3  0.010238   11.23%   [[[[[[[[
   --------
   0.091182
```

Appendix 7 Site 4 (continued).

Row Contributions

I	NAME	QLT	MAS	INR	k=1	COR	CTR	k=2	COR	CTR
1	1	885	11	48	576	885	59	11	0	0
2	2	816	0	5	793	209	1	1349	606	18
3	6	975	99	364	573	974	492	-14	1	1
4	7	919	24	76	512	909	95	-52	9	4
5	13	995	0	1	-1716	982	2	201	13	0
6	20	816	2	69	793	209	20	1349	606	251
7	22	816	0	15	793	209	4	1349	606	54
8	24	981	15	56	576	980	74	-11	0	0
9	30	816	0	[illegible]	793	209	1	1349	606	18
10	32	861	16	14	240	858	14	15	3	0
11	33	797	15	19	-294	793	20	-22	5	1
12	36	784	2	74	466	73	7	-1459	711	317
13	38	691	3	28	614	391	15	-4	0	0
14	40	566	4	31	455	333	14	-395	243	46
15	41	810	0	5	712	184	1	1312	625	18
16	44	816	0	5	793	209	1	1349	606	18
17	45	816	0	10	793	209	3	1349	606	36
18	46	816	0	5	793	209	1	1349	606	18
19	47	816	0	5	793	209	1	1349	606	18
20	49	641	2	30	524	138	6	-917	483	86
21	50	717	13	3	-77	273	1	98	444	8
22	53	810	1	23	719	187	6	1315	624	88
23	55	1000	792	115	-115	999	159	2	0	0

Column Contributions

J	NAME	QLT	MAS	INR	k=1	COR	CTR	k=2	COR	CTR
1	A	924	250	204	203	555	157	166	369	455
2	S	876	250	146	120	271	55	-180	605	533
3	C	325	250	116	117	322	52	-11	3	2
4	V	999	250	534	-440	996	736	25	3	10

Appendix 7 Site 5.

Input
24 4 0 2
Output
1 1 1 1 1
Columns
A,S,C,V
Template
1111
Graphs
12002 3311
Data

1	1382	17	500	14
6	4369	0	0	0
7	583	2985	980	0
11	89	0	0	0
14	45	0	0	0
20	490	0	0	0
22	89	0	0	0
24	1560	0	0	0
28	45	0	0	0
30	178	1493	0	8
32	2316	2540	1870	25
33	1560	1340	1000	596
35	89	0	0	0
36	0	90	0	1
38	267	1493	0	70
41	45	200	0	5
44	45	400	0	0
47	1605	300	0	90
49	0	0	0	16
50	1962	2985	1780	90
51	0	90	0	1
52	0	90	0	0
53	357	0	0	0
55	82925	85978	93870	99084

Inertias and percentages of inertia

1	0.073324	60.93%	[[[
2	0.042558	35.37%	[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[
3	0.004456	3.70%	[[[
	0.120339		

Appendix 7   Site 5 (continued).

Row Contributions

I	NAME	QLT	MAS	INR	k=1	COR	CTR	k=2	COR	CTR
1	1	920	5	54	-1118	918	82	-49	2	0
2	6	996	11	272	-1726	993	444	95	3	2
3	7	991	11	92	329	111	17	927	880	230
4	11	996	0	6	-1726	993	9	95	3	0
5	14	996	0	3	-1726	993	5	95	3	0
6	20	996	1	31	-1726	993	50	95	3	0
7	22	996	0	6	-1726	993	9	95	3	0
8	24	996	4	97	-1726	993	158	95	3	1
9	28	996	0	3	-1726	993	5	95	3	0
10	30	947	4	77	431	84	11	1381	863	188
11	32	794	17	48	-206	124	10	480	671	91
12	33	965	11	10	-216	443	7	234	522	14
13	35	996	0	6	-1726	993	9	95	3	0
14	36	952	0	6	686	162	1	1518	791	12
15	38	928	5	67	331	63	7	1232	865	163
16	41	934	1	9	251	37	1	1232	897	22
17	44	950	1	21	443	86	3	1401	863	51
18	47	978	5	70	-1259	939	108	256	39	8
19	49	573	0	1	585	114	0	-1173	458	1
20	50	877	17	53	-70	13	1	567	864	129
21	51	952	0	6	686	162	1	1518	791	12
22	52	956	0	6	687	157	1	1547	798	13
23	53	996	1	22	-1726	993	36	95	3	0
24	55	996	985	37	46	419	26	-54	576	61

Column Contributions

J	NAME	QLT	MAS	INR	k=1	COR	CTR	k=2	COR	CTR
1	A	1000	250	455	-467	998	745	20	2	2
2	S	996	250	285	186	253	118	319	743	599
3	C	681	250	75	123	419	51	-97	261	55
4	V	936	250	186	159	281	86	-242	655	344

Appendix 7 Site 6.

Input
25 4 0 2
Output
1 1 1 1 1
Columns
A,S,C,V
Template
1111
Graphs
12002 3311
Data

1	823	70	90	14
6	2789	1150	1970	0
7	594	0	0	0
14	46	0	0	0
20	412	0	2083	0
24	1326	930	1130	0
30	320	0	0	0
31	1006	0	0	0
32	3292	4060	4460	1420
33	1143	1960	1250	1062
35	183	0	0	0
36	10	0	83	1
38	91	0	500	1
40	46	0	200	1
43	0	0	300	2
44	0	0	300	3
45	91	0	0	0
46	0	0	500	1
48	0	0	100	2
49	46	0	100	6
50	2881	1990	2083	1420
51	0	0	0	2
52	46	980	650	2
53	183	0	0	0
55	84672	88860	84210	96064

Inertias and percentages of inertia

1	0.032348	45.27%	[[
2	0.031345	43.86%	[[
3	0.007769	10.87%	[[[[[[[[[[[[[[
	0.071462		

Appendix 7 Site 6 (continued).

Row Contributions

I	NAME	QLT	MAS	INR	k=1	COR	CTR	k=2	COR	CTR
1	1	997	2	62	880	435	60	-1000	562	79
2	6	972	15	101	671	925	206	-152	47	11
3	7	990	1	62	1042	362	50	-1373	628	89
4	14	990	0	5	1042	362	4	-1373	628	7
5	20	944	6	166	911	438	160	980	506	191
6	24	813	8	43	540	809	76	-35	3	0
7	30	990	1	34	1042	362	27	-1373	628	49
8	31	990	3	106	1042	362	84	-1373	628	151
9	32	616	33	58	232	432	55	151	184	24
10	33	64	14	13	-52	39	1	42	25	1
11	35	990	0	19	1042	362	15	-1373	628	27
12	36	945	0	7	879	357	6	1129	589	10
13	38	945	1	40	906	421	38	1010	523	48
14	40	940	1	15	906	466	16	914	475	16
15	43	956	1	31	871	257	18	1435	699	50
16	44	955	1	31	864	255	17	1430	700	49
17	45	990	0	10	1042	362	8	-1373	628	14
18	46	957	1	52	881	260	30	1442	697	83
19	48	952	0	10	842	249	6	1414	703	16
20	49	902	0	6	845	649	8	530	254	3
21	50	956	21	18	211	723	29	-120	233	10
22	51	599	0	0	-1335	592	0	-145	7	0
23	52	330	4	57	23	1	0	564	329	43
24	53	990	0	19	1042	362	15	-1373	628	27
25	55	916	885	36	-51	904	71	-6	11	1

Column Contributions

J	NAME	QLT	MAS	INR	k=1	COR	CTR	k=2	COR	CTR
1	A	998	250	330	187	372	271	-243	625	471
2	S	361	250	112	-107	356	88	13	5	1
3	C	989	250	321	159	176	196	256	713	522
4	V	861	250	236	-240	852	444	-26	10	5

Appendix 7 Site 7.

Input
25 4 0 2
Output
1 1 1 1 1
Columns
A,S,C,V
Template
1111
Graphs
12002 3311
Data

1	3520	2680	1130	71
6	5085	4960	5930	0
7	3433	2990	1920	0
20	869	0	0	0
22	43	0	0	0
24	2347	1026	1790	0
28	391	0	0	0
30	87	0	0	0
32	2521	1850	1395	0
33	1217	513	930	1957
34	0	0	0	10
35	0	513	0	3
36	0	500	930	1
37	43	513	0	0
38	348	0	0	8
39	0	0	0	4
40	174	513	290	410
44	87	0	0	5
46	43	0	0	3
47	43	0	0	2
49	174	0	0	28
50	1608	970	465	932
52	217	250	270	1
53	435	0	0	2
55	77314	83223	84949	96558

Inertias and percentages of inertia

1	0.054207	66.76%	[[
2	0.020183	24.86%	[[[[[[[[[[[[[[[[[[[
3	0.006812	8.39%	[[[[[[
	0.081202		

Appendix 7 Site 7 (continued).

Row Contributions

I	NAME	QLT	MAS	INR	k=1	COR	CTR	k=2	COR	CTR
1	1	899	19	119	684	894	160	52	5	2
2	6	957	40	168	477	665	168	-316	292	198
3	7	960	21	103	613	932	144	-107	28	12
4	20	991	2	80	1289	554	67	1145	437	141
5	22	991	0	4	1289	554	3	1145	437	7
6	24	843	13	74	626	854	93	-29	2	1
7	28	991	1	36	1289	554	30	1145	437	63
8	30	991	0	8	1289	554	7	1145	437	14
9	32	993	14	73	636	986	108	-54	7	2
10	33	937	12	30	-278	371	16	344	567	67
11	34	996	0	1	-1509	759	1	842	236	1
12	35	307	1	46	219	17	1	-914	290	54
13	36	867	4	52	68	4	0	-1008	863	180
14	37	974	0	3	1047	696	3	661	277	3
15	38	991	1	31	1226	532	25	1138	459	57
16	39	996	0	0	-1509	759	0	842	236	0
17	40	519	3	6	-199	294	3	-174	226	5
18	44	991	0	7	1137	499	5	1129	492	15
19	46	991	0	4	1106	487	3	1125	504	7
20	47	991	0	4	1164	510	3	1132	481	7
21	49	992	1	13	901	397	8	1103	595	30
22	50	870	10	20	225	301	9	309	569	47
23	52	986	2	8	451	597	7	-364	389	12
24	53	991	1	40	1276	549	33	1144	441	71
25	55	1000	855	70	-81	991	104	8	9	3

Column Contributions

J	NAME	QLT	MAS	INR	k=1	COR	CTR	k=2	COR	CTR
1	A	998	250	359	500	772	415	163	227	328
2	S	602	250	108	57	94	15	-134	509	221
3	C	630	250	108	-6	1	0	-149	629	273
4	V	999	250	424	-351	896	569	120	104	177

Appendix 7 Site 9.

Input
30 4 0 2
Output
1 1 1 1 1
Columns
A,S,C,V
Template
1111
Graphs
12002 3311
Data

1	1786	1170	1760	707
6	3333	2800	1060	0
7	159	80	0	0
9	0	0	0	2
11	40	10	0	10
12	0	0	0	2
20	397	1449	0	0
22	40	362	0	0
23	40	10	0	0
24	675	490	1887	0
28	40	0	0	16
30	40	0	1887	0
32	2897	1087	2050	90
33	1944	1449	1887	8
35	40	0	0	0
36	0	362	0	1
37	40	0	0	0
38	675	0	0	9
40	357	0	670	0
41	0	362	940	2
43	0	0	0	1
44	79	0	0	0
46	0	725	870	8
47	40	0	0	0
49	40	0	0	80
50	3175	2260	387	1080
52	79	362	980	85
53	317	0	0	0
54	0	0	970	0
55	83770	87021	83153	97900

Inertias and percentages of inertia

1	0.045434	47.61%	[[
2	0.032577	34.14%	[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[
3	0.017426	18.26%	[[[[[[[[[[[[[[[[[[[
	0.095434		

Appendix 7 Site 9 (continued).

Row Contributions

I	NAME	QLT	MAS	INR	k=1	COR	CTR	k=2	COR	CTR
1	1	964	14	16	220	444	14	238	520	24
2	6	944	18	104	-99	18	4	715	926	282
3	7	991	1	8	-392	126	2	1027	863	19
4	9	874	0	0	-867	251	0	-1368	624	0
5	11	766	0	2	-454	206	1	748	560	3
6	12	874	0	0	-867	251	0	-1368	624	0
7	20	306	5	80	-459	128	21	542	178	42
8	22	176	1	24	-477	100	5	418	76	5
9	23	878	0	2	-371	80	0	1172	798	5
10	24	999	8	66	897	971	135	153	28	5
11	28	440	0	2	-491	177	1	600	263	2
12	30	999	5	143	1658	968	291	-294	30	13
13	32	919	15	75	308	201	32	581	717	159
14	33	985	13	49	345	340	35	475	645	92
15	35	680	0	3	-341	39	0	1387	641	6
16	36	113	1	28	-493	82	5	306	31	3
17	37	680	0	3	-341	39	0	1387	641	6
18	38	672	2	52	-348	42	5	1351	630	96
19	40	888	3	32	990	827	55	267	60	6
20	41	870	3	47	1088	853	85	-154	17	2
21	43	874	0	0	-867	251	0	-1368	624	0
22	44	680	0	6	-341	39	1	1387	641	12
23	46	488	4	42	696	486	43	-45	2	0
24	47	680	0	3	-341	39	0	1387	641	6
25	49	557	0	4	-692	392	3	-460	165	2
26	50	997	21	28	9	1	0	358	997	83
27	52	916	4	37	921	894	70	-144	22	2
28	53	680	1	25	-341	39	2	1387	641	47
29	54	1000	2	76	1700	963	154	-330	36	8
30	55	980	880	42	-42	395	35	-51	585	72

Column Contributions

J	NAME	QLT	MAS	INR	k=1	COR	CTR	k=2	COR	CTR
1	A	803	250	222	-73	62	29	250	740	481
2	S	234	250	159	-105	182	60	56	52	24
3	C	1000	250	353	362	974	722	-59	26	27
4	V	935	250	266	-185	336	188	-247	599	468

Appendix 7   Site 10.

Input
22 4 0 2
Output
1 1 1 1 1
Columns
A,S,C,V
Template
1111
Graphs
12002   3311
Data

6	4805	3750	4520	0
7	641	0	0	0
14	53	0	0	0
20	694	0	0	0
24	961	2941	1060	0
28	107	0	0	0
30	107	0	0	0
32	5713	4860	3970	11
33	1014	980	610	1078
34	0	7	0	6
35	53	0	0	0
36	0	660	0	1
38	374	660	0	14
40	214	0	0	90
41	534	0	0	8
43	0	0	0	2
44	53	0	0	0
46	0	0	980	2
49	53	0	0	6
50	3257	2941	3571	1780
53	214	0	0	7
55	81153	83201	85289	96995

Inertias and percentages of inertia

```
1  0.040244  53.89%  [[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[[
2  0.021107  28.26%  [[[[[[[[[[[[[[[[[[[[[[[[[[[[
3  0.013328  17.85%  [[[[[[[[[[[[[[[[[[
   --------
   0.074578
```

Appendix 7 Site 10 (continued).

Row Contributions

I	NAME	QLT	MAS	INR	k=1	COR	CTR	k=2	COR	CTR
1	6	881	33	152	649	867	245	69	14	7
2	7	978	2	64	1115	414	49	-1300	564	128
3	14	978	0	5	1115	414	4	-1300	564	11
4	20	978	2	70	1115	414	54	-1300	564	139
5	24	901	12	123	493	329	75	649	572	248
6	28	978	0	11	1115	414	8	-1300	564	21
7	30	978	0	11	1115	414	8	-1300	564	21
8	32	998	36	175	596	985	321	66	12	8
9	33	159	9	5	-34	30	0	-71	129	2
10	34	478	0	0	-489	236	0	494	242	0
11	35	978	0	5	1115	414	4	-1300	564	11
12	36	683	2	66	457	70	9	1354	613	143
13	38	539	3	38	666	405	29	383	134	18
14	40	927	1	14	312	73	2	-1067	854	41
15	41	976	1	52	1075	400	39	-1289	576	107
16	43	936	0	0	-1595	849	0	-511	87	0
17	44	978	0	6	1115	414	4	-1300	564	11
18	46	69	2	98	17	0	0	453	69	24
19	49	966	0	4	839	310	3	-1220	656	10
20	50	701	29	21	192	671	26	41	30	2
21	53	975	1	20	1029	384	14	-1275	591	43
22	55	993	867	58	-70	974	105	-10	20	4

Column Contributions

J	NAME	QLT	MAS	INR	k=1	COR	CTR	k=2	COR	CTR
1	A	990	250	290	224	577	311	-189	412	423
2	S	789	250	201	92	142	53	197	647	460
3	C	106	250	139	4	0	0	66	105	52
4	V	997	250	370	-320	927	636	-74	50	65

Appendix 7 Site 11.

Input
35 4 0 2
Output
1 1 1 1 1
Columns
A,S,C,V
Template
1111
Graphs
12002 3311
Data

1	1071	1960	970	167
4	0	0	0	2
5	0	0	0	10
6	20896	15560	18560	53
7	436	250	90	63
8	0	0	0	2
9	0	0	0	44
11	0	0	0	135
13	0	0	0	24
14	0	0	0	20
16	0	0	0	8
17	159	90	60	51
18	0	0	0	8
19	0	0	0	5
20	1308	940	560	31
22	40	0	0	0
23	0	0	0	2
24	1110	870	1149	212
25	0	0	0	2
29	159	0	0	0
30	159	0	0	9
32	1665	0	1149	4
33	1150	2650	2070	1740
35	40	0	0	0
36	50	0	49	1
38	317	0	0	7
40	79	0	0	2
41	198	0	0	4
44	119	0	600	0
45	40	0	0	0
46	0	980	600	98
48	0	0	0	2
49	40	0	0	4
50	3053	1060	1530	980
55	67912	75640	72712	96311

Inertias and percentages of inertia

1	0.080635	78.44%	[[[
2	0.016349	15.90%	[[[[[[[[[[
3	0.005810	5.65%	[[[[
	0.102795		

Appendix 7   Site 11 (continued).

Row Contributions

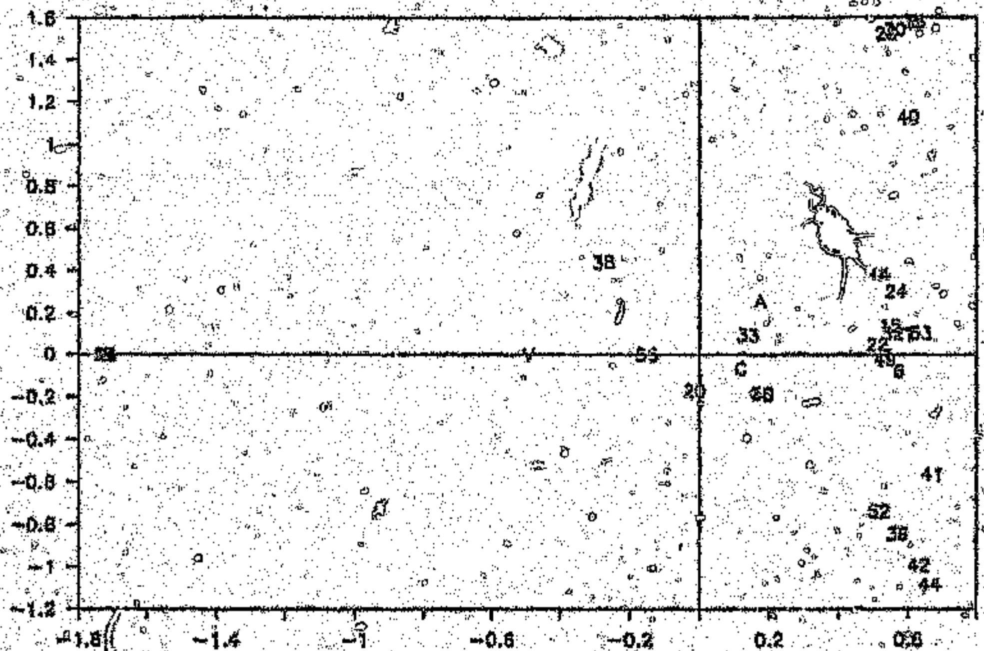
I	NAME	QLT	MAS	INR	k=1	COR	CTR	k=2	COR	CTR
1	1	788	10	38	367	361	17	-393	416	99
2	4	999	0	0	-1635	891	0	569	108	0
3	5	999	0	1	-1635	891	1	569	108	0
4	6	999	138	468	587	987	589	-64	12	35
5	7	632	2	10	502	500	7	258	132	9
6	8	999	0	0	-1635	891	0	569	108	0
7	9	999	0	3	-1635	891	4	569	108	2
8	11	999	0	10	-1635	891	11	569	108	7
9	13	999	0	2	-1635	891	2	569	108	1
10	14	999	0	1	-1635	891	2	569	108	1
11	16	999	0	1	-1635	891	1	569	108	0
12	17	743	1	2	336	509	1	228	234	3
13	18	999	0	1	-1635	891	1	569	108	0
14	19	999	0	0	-1636	891	0	569	108	0
15	20	800	7	31	593	793	31	54	7	1
16	22	907	0	3	1039	360	1	1282	548	10
17	23	999	0	0	-1635	891	0	569	108	0
18	24	966	8	16	437	946	20	-64	20	2
19	25	999	0	0	-1635	891	0	569	108	0
20	29	907	0	12	1039	360	5	1282	548	40
21	30	905	0	11	895	309	4	1244	595	40
22	32	896	7	73	809	617	57	544	279	128
23	33	993	19	15	-46	26	1	-281	967	92
24	35	907	0	3	1039	360	1	1282	548	10
25	36	729	0	2	741	571	2	390	158	2
26	38	907	1	22	981	340	10	1267	567	79
27	40	906	0	6	973	337	2	1264	569	20
28	41	907	1	14	986	342	6	1268	565	50
29	44	217	2	26	592	199	7	-177	18	3
30	45	907	0	3	1039	360	1	1282	548	10
31	46	993	4	36	143	23	1	-929	970	221
32	48	999	0	0	-1635	891	0	569	108	0
33	49	904	0	3	796	271	1	1217	633	10
34	60	991	17	41	367	531	28	342	461	118
35	55	1000	781	146	-138	994	186	11	6	6

Column Contributions

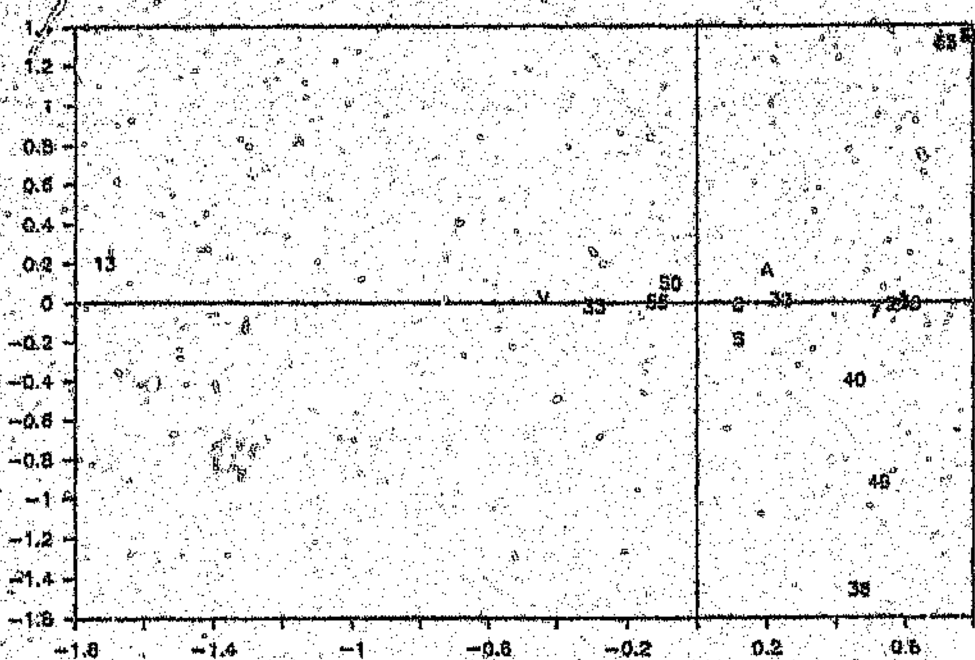
J	NAME	QLT	MAS	INR	k=1	COR	CTR	k=2	COR	CTR
1	A	986	250	281	295	753	270	164	233	411
2	S	806	250	90	32	27	3	-170	779	440
3	C	619	250	92	138	500	59	-67	119	69
4	V	1000	250	537	-464	976	668	73	24	81

Appendix 8 Graphical output of CA of sites 3 - 11.

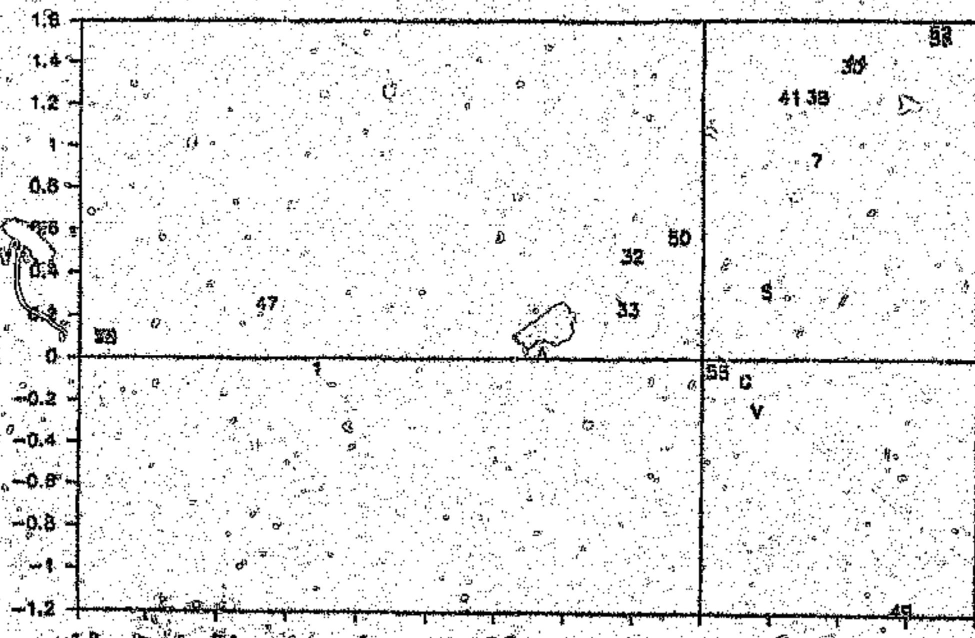
Appendix 8 Site 3.



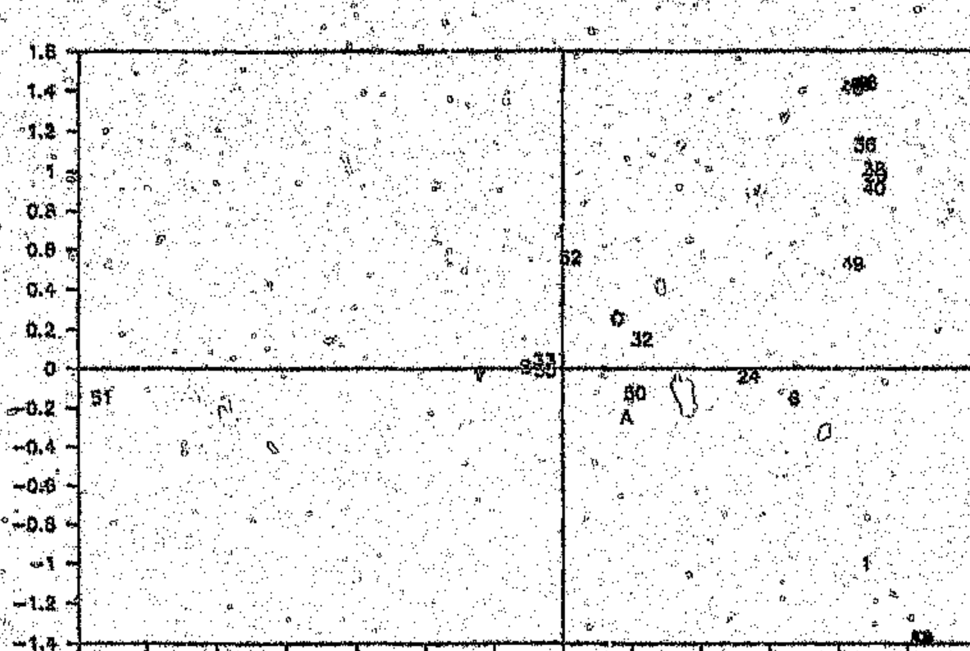
Appendix 8 Site 4.



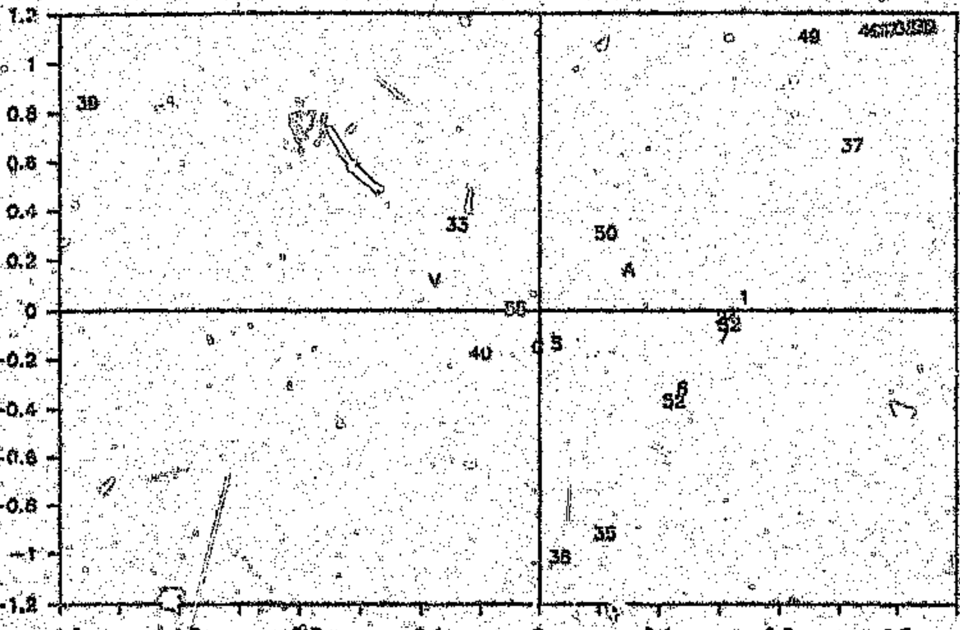
Appendix 8 Site 5.



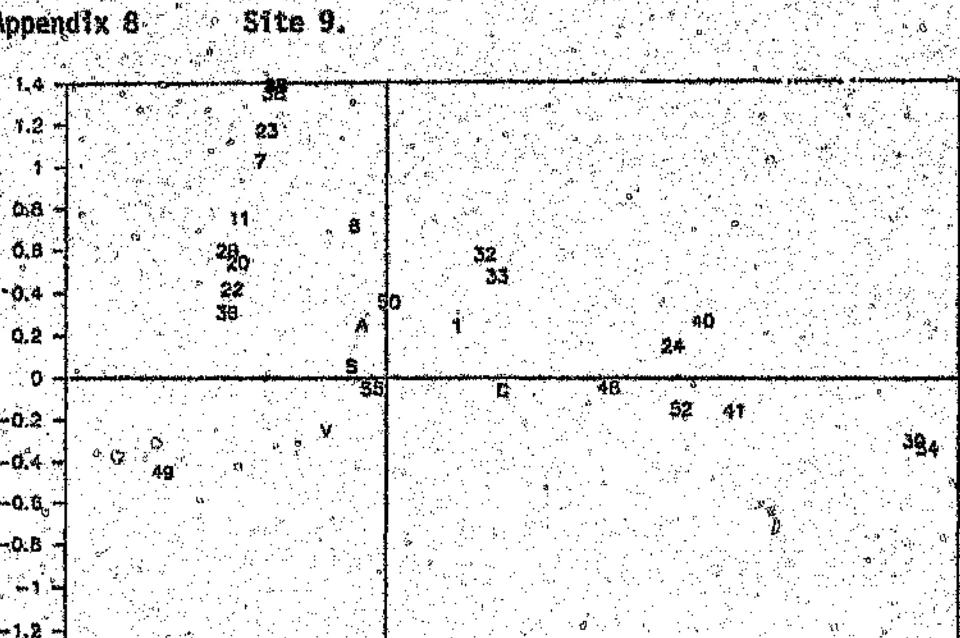
Appendix 8 Site 6.



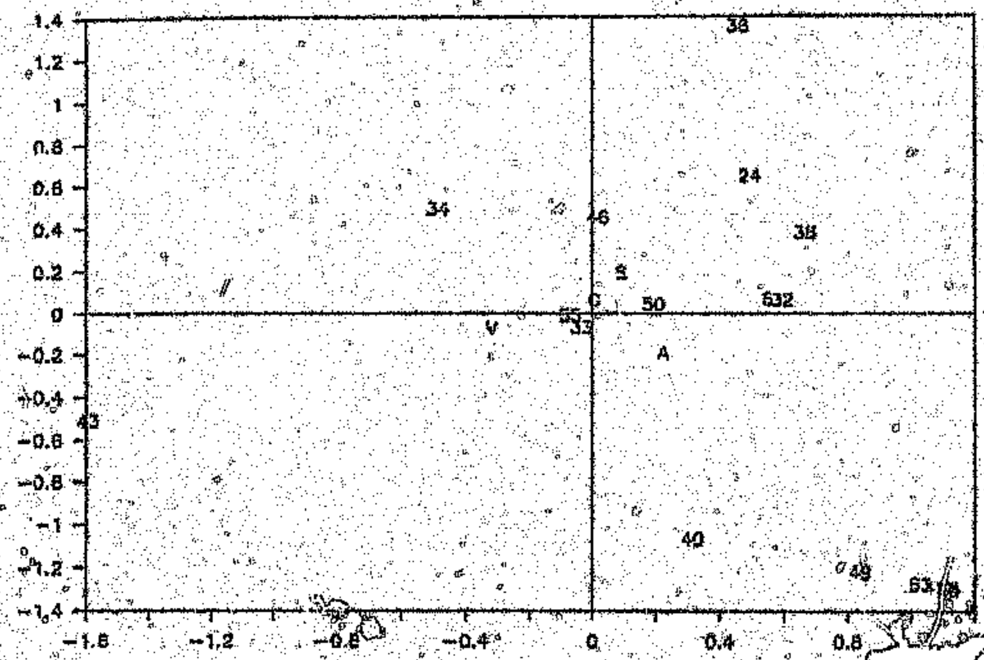
Appendix 8 Site 7.



Appendix 8 Site 9.



Appendix 8 Site 10.



Appendix 8 Site 11.