

FIELD EVALUATION OF RAGWEED POLLEN SAMPLERS

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INTRODUCTION

IN 1953 AND 1954, the Durham sampler was used in a survey of air-borne pollen grains and fungus spores made at thirty-five locations in New York State.¹ At several of these locations, identical samplers of other agencies were operated nearby, but at different heights, for sampling ragweed pollen. Comparisons of data revealed unexplained differences in ragweed pollen count. In general, the higher counts were obtained at the higher elevations. Since previous studies²⁻⁸ had revealed high counts of pollen and spores at altitudes of several thousand feet, and as routine sampling is conducted at varying elevations, it seemed desirable to study the variation in ragweed pollen concentrations in the lowest few hundred feet of the atmosphere. To accomplish this, a cooperative project was undertaken by the State Botanist's Office of the New York State Museum and Science Service and the Meteorology Group of Brookhaven National Laboratory. Field studies were begun during the 1955 pollen season at the Laboratory, which is located in central Long Island, New York.

Sampling was conducted at eight levels, from 9 to 410 feet, on a 420-foot meteorology tower, a triangular structure of open steelwork and constant dimensions from bottom to top. During analysis of the data, it was concluded that the sampling methods being used gave results that were influenced by a number of variables in addition to the concentration of ragweed pollen. Because of this, no conclusion was possible concerning the variation of concentration with height, but a number of experiments were initiated which were designed to give a better evaluation of the sampling methods.

EFFECTS OF WIND DIRECTION ON SLIDES

The 1955 sampling array included two Durham samplers mounted 2 feet apart on the railing at each of the eight tower levels. The mounting technique conformed with recommendations of the Pollen Survey Committee of the Research Council of the American Academy of Allergy.⁹ One of each pair was

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mounted with the long axis of its slide in a north-south position, and the other sampler was mounted with the long axis in an east-west position. The greased slides were changed daily at 0800 from August 22 to September 9. Fig. 1 summarizes the data from the samples at the various levels.

Inspection of the pollen counts showed that at all levels the north-south (N-S) slide usually took more pollen than the east-west (E-W) slide. Throughout the sampling period, slide N-S took 9,226 grains, or 58 per cent of the total, while slide E-W took 6,628 grains, or 42 per cent of the total. Since wind direction was judged to be the only meteorological variable capable of producing

TOTAL COUNT (8 SQ. CM.) (16 DAYS)	AV. PER CU. YD.	HAY- FEVER DAYS	INDEX	S L I D E	TOWER HEIGHT (FT.)	S L I D E	TOTAL COUNT (8 SQ. CM.) (20 DAYS)	AV. PER CU. YD.	HAY- FEVER DAYS	INDEX
1606	64	9	20	N-S	410					
1114	45	11	17	E-W	355		N-S 1678	50	12	19
							E-W 1690	51	12	19
1524	61	13	21	N-S	300		O 1582	45	12	19
1331	53	12	19	E-W			L 1538	46	12	18
							C 570	17	5	8
1400	56	12	20	N-S						
886	35	10	14	E-W	150		N-S 1180	35	11	16
1129	45	9	15	N-S			E-W 1020	31	9	13
734	29	8	12	E-W			O 1066	32	12	16
905	36	7	13	N-S	75		L 898	27	8	13
668	27	7	10	E-W			C 411	12	3	5
997	40	9	15	N-S	37		N-S 1088	33	8	13
631	25	8	11	E-W	18		E-W 727	22	9	12
939	38	7	12	N-S	9		N-S 944	28	7	12
671	27	7	10	E-W			E-W 731	22	4	7
726	29	6	10	N-S						
593	24	7	10	E-W						

Fig. 1.—Comparison of data computed from Durham sampler pollen counts at different altitudes during 1955 and 1956. The figures in the total count column are not converted to a volumetric basis. Average per cubic yard is determined by multiplying the average number of pollen grains per square centimeter by 3.6. A hay fever day has an average of 25 or more grains per cubic yard. The ragweed pollen index is obtained by converting the data to a volumetric basis, then assigning one point for each hay fever day, one point for each 100 grains of pollen on the day of the highest count, and one point for each 200 grains of pollen in the seasonal total. "Slide" refers to the orientation of the slide. N-S, Slide with long axis pointing north and south; E-W, slide with long axis east and west; O, round slide in a circular holder; L, slide with long axis parallel to direction of air flow; C, slide with long axis at right angles to air flow. The tower heights are in feet.

these results, an analysis of the hourly wind data taken during the period was made. The 355-foot direction was chosen as representative. For each day, the percentage of hours during which a wind came from each of the four quadrants was computed. The percentages from north and south were then added, as were

the percentages from east and west. For the period as a whole, north or south winds prevailed 53 per cent of the time and east or west 47 per cent, which indicated that the difference in pollen capture might be related to the wind direction.

In 1956 the same slide orientation was repeated at each of four levels. Midway through the experiment, the positions (but not the orientation) of the samplers at each level were reversed with no change in the trend. Once again, at all except the top level, the N-S slides took considerably more pollen than the E-W slides beside them (Fig. 1), while the N-S wind direction again predominated. These data with respect to slide orientation are not in agreement with those reported by other investigators¹⁰ who found little correlation between placement and pollen capture.

In order that the effect of slide orientation with respect to wind direction might be investigated better, another experiment was conducted in 1956. Pairs of Durham samplers were mounted on two wind vanes. One slide of each pair was placed with its long axis parallel to the vane; the other was placed with its long axis at right angles to the vane. Thus, slide L continuously had the air flow over its length while slide C had the flow over its width. The vanes were mounted at 150 and 355 feet, and the slides were changed daily for a twenty-day period. On seventeen of the twenty days, higher counts were obtained at both levels on the lengthwise (L) slides. As shown in Fig. 1, the total L slide count was more than double that of the C slide at the 150-foot level (a ratio of 2.2 to 1) and nearly three times as large (a ratio of 2.7 to 1) at 355 feet.

In 1957 a further check of this effect was made. Two wind tunnels were constructed and mounted approximately 4 feet above the ground in an open field near the tower. Each tunnel was 30 inches in diameter and 9 feet in length. Each had a two-speed fan mounted at one end to provide suction, and a totalizing anemometer was mounted inside to record the total air passage. In each tunnel, a lengthwise and a crosswise slide were mounted and changed daily for a thirteen-day period. The fan in tunnel 1 was run at its fast speed, giving an average air flow of 8.0 m.p.h., while the slow speed of the fan in tunnel 2 gave an average of 4.2 m.p.h. In tunnel 1, 1,568 grains were taken on slide L and 307 on slide C, a ratio of 5.1 to 1. In tunnel 2, 1,051 grains were collected on slide L and 395 on slide C, a ratio of 2.8 to 1.

Both the vane and the tunnel tests show that a slide oriented parallel with the air flow collects a great deal more pollen than one oriented at right angles and that the difference is greater at higher wind speeds. Since the reasons for this effect were believed to be purely aerodynamic, the flow patterns over the slides were investigated in a wind tunnel recently constructed at Brookhaven. Wind speeds in the tunnel may be varied from zero to 45 m.p.h. Oil-fog smoke is produced by a small generator and introduced into the tunnel to allow visual observation and photography of the air flow past objects under test. The sampling devices used in our field studies were tested at air speeds of 6 and 15 m.p.h., which are representative of the range of speeds encountered in actual field sampling.

Fig. 2 shows typical flow patterns over a microscope slide in the standard Durham holder. It can be seen that as the air approaches the blunt leading edge of the slide and its holder it is forced to diverge from its course. As shown in Fig. 2, *A* and *B*, a small rise occurs over the leading surface of the slide at 6 m.p.h., but a much larger one takes place at 15 m.p.h. Thus, as the speed of the air approaching the slide increases, the proportion of that air which is effectively sampled decreases and the pollen collected tends to deposit toward the rear of the slide. In spite of the decreased proportions of air sampled at increasing wind speeds, our field tests show that the greater volume of air sampled results in a greater over-all catch. Fig. 2, *C* and *D*, shows the flow patterns as the air passes over the short axis of the slide. At 6 m.p.h. the rise

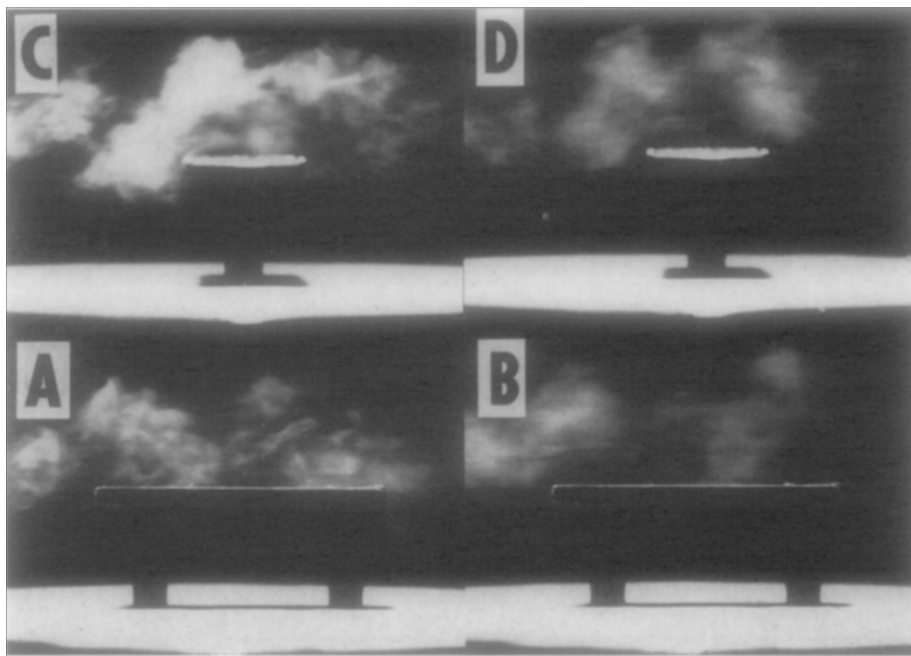


Fig. 2.—Wind-tunnel photographs of flow patterns over a slide in a Durham holder. Air flow is from left to right. *A*, Slide lengthwise, air speed 6 m.p.h. *B*, Slide lengthwise, air speed 15 m.p.h. *C*, Slide crosswise, airspeed 6 m.p.h. *D*, Slide crosswise, air speed 15 m.p.h.

over the leading surface of the slide carries the air past the middle before it descends, while at 15 m.p.h. the air is effectively lifted over the entire surface. These flow patterns explain the smaller catch obtained on a slide oriented across the wind.

These findings are further confirmed by counts which were made on the two halves of the lengthwise slides exposed in the tunnels in 1957. The front half of the slides took 1,026 grains, or 37 per cent of the total, while the back half captured 1,778, or 63 per cent of the total. These figures reinforce the observations that the air approaching the leading edge of the slide is forced to rise, carrying much of the pollen over the first inch or so of the slide. Thus, in an air flow over the long axis of the slide, most of the pollen is caught on the back half, while in an air flow over the short axis, much of the pollen passes

completely over the slide. This is confirmed by the much smaller catch on the slides oriented across the wind in the tests made in 1957 and by the approximately equal catches on both halves.

EFFECTS OF WIND SPEED ON SLIDES

As shown in Fig. 1, the amount of pollen collected on the slides in both 1955 and 1956 showed a fairly uniform increase from the bottom to the top of the tower, with the catch at the top about double that at the bottom. This might have been interpreted as indicating an actual increase in concentration with height had not simultaneous filter samples shown the opposite trend. It was soon realized, however, that the catch on the slides was a function not only of the concentration of pollen in the air but also of the amount of air which passed over the slide. Therefore, the slides exposed to the higher wind speeds at the top of the tower sampled a greater volume of air and caught a larger quantity of pollen.

In order to test this effect under more controlled conditions, slides were exposed in both 1956 and 1957 in the wind tunnels previously described. In 1956, the average tunnel air flows were 5.1 and 8.3 m.p.h., while their total pollen counts were 1,144 and 1,465 grains. In 1957, the air flows were 4.2 and 8.0 m.p.h., and the pollen catches were 1,446 and 1,875 grains. Thus, in both years, a 3 to 4 m.p.h. increase in wind speed gave about a 30 per cent increase in the pollen catch. Actually, the effect was even more marked in 1957 if we consider only the lengthwise slides. Here the total catches were 1,051 and 1,568 grains, an increase of 49 per cent in the faster tunnel.

The slides used in the vane samplers in 1956 give additional evidence. The lengthwise slide at 150 feet, where the wind speed averaged 4.7 m.p.h., took 898 grains, while that at 355 feet, exposed to an average speed of 6.0 m.p.h., took 1,538, a 71 per cent increase. The crosswise slides showed less difference—411 and 570 counts or a 39 per cent increase.

EFFECTS OF WIND SPEED ON FILTER SAMPLERS

In both 1955 and 1956, the slide samples on the tower were augmented by samples taken at several levels on Millipore (molecular membrane) filters mounted in filter holders of a type then in use at Brookhaven.¹¹ Air was drawn through the filters by an electric vacuum pump at the rate of 0.75 cubic feet per minute. In contrast to the slide samples, the filter counts showed a marked decrease with height in 1955 and a similar but less marked trend in 1956. This indicated that the increase of wind speed with height might have an effect on the filter samplers opposite to its effect on the slides.

In 1956, filter samplers were mounted in both wind tunnels and changed daily to check the effect of wind speed on their efficiency. The twenty-four hour period between changes proved to be too long, for the filters became so heavily loaded with dust, as well as pollen, that accurate counting was impossible and the data were discarded. In 1957 the experiment was repeated, with the filters changed automatically every six hours by the automatic programming filter

sampler.¹² On all but one of the eleven days, the filter in the slow tunnel caught considerably more pollen than the one in the fast tunnel. The totals for the period were 3,082 and 1,051 grains, a ratio of nearly 3 to 1, although the same volume of air was pulled through both filters and the concentrations of pollen in the volumes sampled must be presumed identical.

The reason for this effect may be readily explained. In order to collect a particle on a filter, the air containing that particle must be drawn through the filter by some suitable means of suction. If the filter holder opening is at right angles to the direction of air flow, the air must make a 90 degree turn to enter the filter. If the particles in the air are very small (less than 1 micron, for instance), they tend to follow the streamlines of the air faithfully at any normal speed. Larger particles also tend to follow the air flow into the filter if they are moving slowly. However, these larger particles, such as ragweed pollen, have enough momentum in an air flow of considerable speed that they tend to continue in their original direction when the air containing them turns to enter the filter. This effect is the same whether the filter holder is mounted upright, upside down, as has been previously suggested,¹³ or on its side. The only difference, except during precipitation, is the negligible effect of gravity on the particle.

If the filter holder is mounted so that its opening is continuously oriented into the wind, good results will be obtained when the air flow through the filter is equal to the wind speed in the free air approaching the filter. If this is not the case, however, the system is subject to the serious errors of anisokinetic sampling discussed by Watson.¹⁴ An excellent summary of the principles of isokinetic sampling is given by Wilcox.¹⁵

The molecular membrane filter has been used by several investigators for the collection of pollen.^{13, 16-18} In contrast to other types of filter media, it has the advantage of retaining the collected material on its surface where it may be viewed under a microscope. Our experience, as well as that of others,¹³ has shown that the recognition of collected ragweed pollen is feasible, provided the filters are not too heavily loaded with other particles. This consideration may limit the flow rate and exposure time for a given filter.

Tests have shown that the efficiency of this filter in retaining particles in the pollen size range is essentially 100 per cent.¹³⁻¹⁷ Several experimenters have been misled by this into assuming that samples taken with the filter are therefore 100 per cent accurate. Due to the source of error just discussed, this is far from the case. In our experiments, for instance, the filter holders were mounted in an upright position normal to the horizontal air flow. The pull of 0.75 cubic foot per minute gave a linear flow of about 2 m.p.h. in contrast to the wind speeds which sometimes reached 20 m.p.h. Thus, it is evident that our filter system (and probably that of previous workers) is efficient only at very low wind speeds. Since this filter material is not adapted for high flow rates and since materials that are so adapted usually collect particles in the interstices of the material where they are not visible, it seems that the collection

of pollen on filters may not be the ideal way to obtain an accurate sample that some have believed it to be. This method is, in fact, subject to objections as serious as those to the gravity slide method.

DISCUSSION

Several previous investigators have realized that the current slide method of pollen sampling is grossly inaccurate.^{5, 18-26} Our experiments show that the combined effects of wind speed and wind direction may introduce differences of over 500 per cent between adjacent samplers and that the number of hay fever days and the ragweed pollen index computed from such data may show wide variations, even though the same concentration is being sampled. Current practice in exposing slides without regard to these variables yields results which cannot be regarded as comparable from one station to the next or from

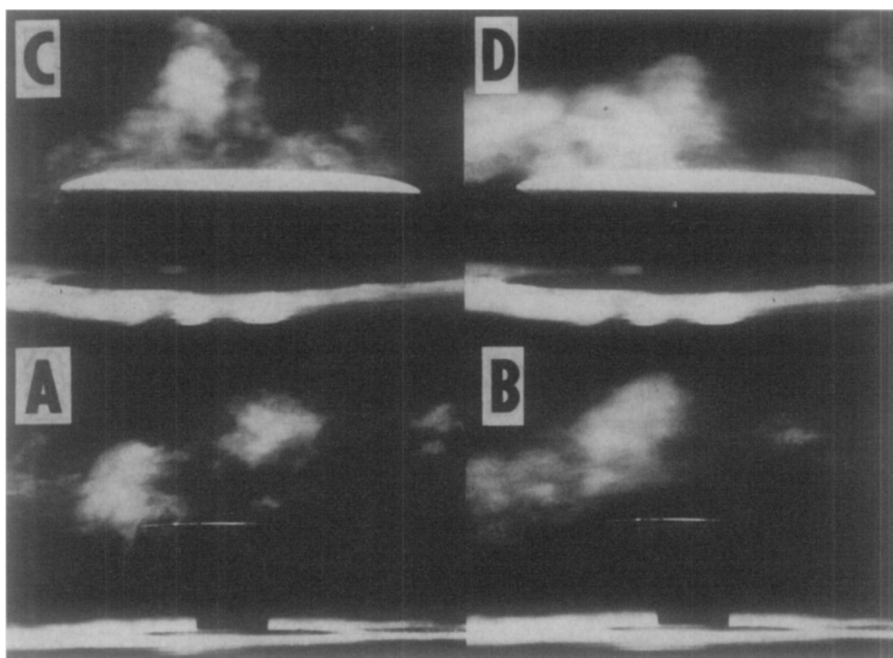


Fig. 3.—Wind-tunnel photographs of flow patterns over round slide holders. Air flow is from left to right. A, Model 1, air speed 6 m.p.h. B, Model 1, air speed 15 m.p.h. C, Model 2, air speed 6 m.p.h. D, Model 2, air speed 15 m.p.h.

one day to the next at the same station. Since comparability is essential in many applications of the pollen count, greater uniformity in sampling is desirable. If the Durham sampler continues to be used, a method should be established to ensure uniform orientation with respect to wind direction. This can easily be accomplished by mounting the sampler on an inexpensive wind vane. Uniform orientation with respect to air flow has been suggested previously²⁷⁻³¹ and is strongly recommended by us.

An alternate method of overcoming the directional bias is the use of a round or square slide in a suitable holder. A round slide holder was used in the 1956 field tests. Experiments have been conducted with other such models and will be continued, but as yet not enough data have been obtained to permit a proper evaluation of their effectiveness. Round slides are more difficult to mount and handle than the rectangular slides, but square slides give little difficulty.

Fig. 3, *A* and *B* shows the flow patterns over the original round-slide holder (Model 1) at 6 and 15 m.p.h. It is obvious that the shape is aerodynamically poor for efficient pollen collection. Fig. 3, *C* and *D* shows the flow patterns over a holder of improved design (Model 2) at the same wind speeds. In contrast to the previous model this holder allows the air to flow smoothly over the surface at both speeds. This holder, with square slides, will be tested in the field during the 1959 season.

Varying wind speeds as a source of error have also been recognized previously^{24, 30, 32-34} and present a more difficult problem than direction. Attempts made by others to reduce or make uniform the rate of air flow over the slides have not resulted in satisfactory counts, since some of the pollen is apparently removed by the obstacles used. Perhaps the most suitable solution is to measure the wind speed or total air passage over the slide and to correct the count by a factor determined either theoretically or experimentally. We have developed an inexpensive anemometer for this purpose, and work is being done toward the determination of a usable correction factor.

Alternate Sampling Methods.—Sampling methods that do not involve slides and filters are still being studied, and these give promise of greater accuracy. Although final evaluations of these devices have not yet been made, brief descriptions may be helpful to other workers.

For short-period samples, the Rotorod sampler²⁵ is believed to be an efficient device. This sampler collects pollen by impaction on a pair of small rods whirled through the air at high speed by a small, inexpensive, battery-operated motor. Single units are not adaptable for long-period samples, since they would become badly overloaded, but a number of units may be operated in sequence by a timing device. A number of these samplers have been constructed at Brookhaven and are currently being tested.

Another method of sampling that shows some promise and is being tried by us is the collection of pollen on the side of a vertical cylinder, a method tested by Gregory.³⁶ The collecting side of the cylinder is kept oriented into the wind by a vane, while an anemometer is used to record the total air flow. Since the efficiency of this device falls off rapidly with decreasing wind speed and increasing cylinder size, only very small cylinders are useful at the lighter wind speeds.

Another device currently under design is an isokinetic sampler which will change its flow rate rapidly and automatically to conform to changes in the wind speed while the sampling intake is oriented into the wind by a vane tail. Although this sampler will be too complex and too expensive for general use, its efficiency should prove very high. It will be used as a standard for the evaluation of other sampling devices.

Numerous other samplers reported in the literature have not been tested by us. Some of these obviously suffer from the same faults as the devices tested. Others may be more efficient but, until a reliable basis for comparison is available, evaluation of the performance of any sampler is subject to many uncertainties.

SUMMARY

Our experiments have shown that pollen capture by the standard Durham sampler is determined by several factors, in addition to the concentration of pollen in the air. Aerodynamic factors are responsible for the greater collecting ability of the slide when its long axis is placed parallel to the air flow. Orientation of the slide with respect to wind direction may result in a 5 to 1 difference in catch between adjacent slides.

It was also found that the amount of pollen captured is a function of the amount of air passing over the slide as well as the concentration of pollen in the air. Thus, an increase of 3 to 4 m.p.h. in the wind speed may give more than a 50 per cent increase in the pollen captured. Since wind speed normally increases with height, elevation of the sampler above the ground determines the wind speed to which the slide is exposed and affects the count.

Tests of a filter sampler showed that this device was also affected by wind speed but in an opposite manner, since efficiency in capturing particles in the pollen size range decreases with increasing wind speed.

Improvements in the standard sampling technique might include vane orientation of the slide sampler and measurement of the air flow which could be used to correct the count, or the use of round or square slides with similar correction of wind speed. Work is continuing on the development and evaluation of other sampling devices.

Maynard E. Smith, Leader of the Meteorology Group at Brookhaven National Laboratory, and Irving A. Singer, Assistant Leader, assisted materially in the planning and conduct of these experiments. Donald M. Lewis of the State Botanist's Office counted all the samples and actively participated in the 1956 and 1957 programs. Louis H. Conger, Jr., formerly Acting Chief of the Bureau of Statistical Services of the New York State Education Department, assisted in the analysis of data. Herbert M. Mapes constructed several modified slide holders.

REFERENCES

1. Ogden, E. C., and Lewis, D. M.: Airborne Pollen and Fungus Spores of New York State, New York State Museum Bull. 378, 1960.
2. Stackman, E. C., Henry, A. W., Curran, G. C., and Christopher, W. N.: Spores in the Upper Air, *J. Ag. Res.* **24**: 599, 1923.
3. MacQuiddy, E. L.: Air Studies at Higher Altitudes, *J. ALLERGY* **6**: 123, 1935.
4. Rempe, H.: Untersuchungen über die Verbreitung des Blütenstaubes durch die Luftströmungen, *Planta* **27**: 93, 1937.
5. Durham, O. C.: Methods in Aerobiology, *J. Aviation Med.* **12**: 152, 1941.
6. Durham, O. C.: Air-borne Fungus Spores as Allergens, *Aerobiology, Am. A. Adv. Sc.* **17**: 32, 1942.
7. Heise, H. A., and Heise, E. R.: The Distribution of Ragweed Pollen and Alternaria Spores in the Upper Atmosphere, *J. ALLERGY* **19**: 403, 1948.
8. Heise, H. A., and Heise, E. R.: The Influence of Temperature Variations and Winds Aloft on the Distribution of Pollens and Molds in the Upper Atmosphere, *J. ALLERGY* **20**: 378, 1949.

9. Durham, O. C.: Report of the National Pollen Survey Committee of the American Academy of Allergy on a Conversion Factor for Gravity Slide Counts, *J. ALLERGY* 18: 284, 1947.
10. Spiegelman, J., and Blumstein, G. I.: Pollen Counts: Variability and Percentage Error in a Given Location Under Standard Conditions, *J. ALLERGY* 22: 536, 1951.
11. Smith, M. E., Bartlett, F. E., and Potts, G. W.: Filter Samplers for Field Use, Presented at the Air Pollution Control Association Annual Meeting, Buffalo, N. Y., May 20-25, 1956.
12. Raynor, G. S.: An Automatic Programming Filter Sampler, *J. Air Pollution Control Assoc.* 7: 122, 1957.
13. Gurney, C. W., and Cryst, S.: Aeroallergen Studies With the Molecular Filter Membrane, *J. ALLERGY* 26: 533, 1955.
14. Watson, H. H.: Errors Due to Anisokinetic Sampling of Aerosols, *Am. Indust. Hyg. A. Quart.* 15: 21, 1954.
15. Wilcox, J. D.: Isokinetic Flow and Sampling of Airborne Particulates in Artificial Stimulation of Rain, New York, 1955, Pergamon Press, Inc., pp. 177-182.
16. Goetz, A.: The Application of Molecular Filter Membranes to the Analysis of Aerosols, *Am. J. Pub. Health* 43: 150, 1953.
17. Gordon, M. A., and Cupp, H. B., Jr.: Detection of *Histoplasma capsulatum* and Other Fungus Spores in the Environment by Means of the Membrane Filter, *Mycologia* 45: 241, 1953.
18. Cryst, S., Gurney, C., and Hansen, W.: A Method for Determining Aero-allergen Concentrations With the Molecular Filter Membrane, *J. Lab. & Clin. Med.* 46: 471, 1955.
19. Durham, O. C.: A Critical Interpretation of Data on the Incidence of Air-borne Allergens, *J. ALLERGY* 13: 31, 1941.
20. Durham, O. C.: The Volumetric Incidence of Atmospheric Allergens. II. Simultaneous Measurements by Volumetric and Gravity Slide Methods. Results With Ragweed Pollen and Alternaria Spores, *J. ALLERGY* 15: 226, 1944.
21. Wodehouse, R. P.: Hayfever Plants, Waltham, Mass., 1945, Chronica Botanica Company.
22. Seltzer, A.: Pollen Counts—Their Proper Place in Hay Fever, *M. Ann. District of Columbia* 16: 542, 1947.
23. Fletcher, A. H., and Velz, C. J.: Pollens—Sampling and Control, *Indust. Med.* 19: 129, 1950.
24. Wiley, J. S., and Tarzwell, C. M.: Preliminary Report on Atmospheric Pollen Studies, Supplement to Proc. Northeastern States Weed Control Conference, pp. 34-50, 1950.
25. Hewson, E. W.: Some Aspects of the Dispersion of Pollens and Industrial Contaminants in Relation to Micrometeorology, Univ. of Mich. Engineering Research Institute, Project 2160, Scientific Report No. 1, 1953.
26. Dingle, A. N.: Hay Fever Pollen Counts and Some Weather Effects, *Bull. Am. Met. Soc.* 38: 465, 1957.
27. Penfound, W. T., and Efron, B. G.: A Standardized Method for Pollen Air Analysis, *Proc. Soc. Exper. Biol. & Med.* 27: 650, 1930.
28. Wilmer, H. B., and Cobe, H. M.: A Note on the Quantitative Survey of Pollen, *J. ALLERGY* 3: 63, 1931.
29. Duke, W. W.: A Rapid and More Accurate Method of Determining the Pollen Count of the Air, *J. A. M. A.* 99: 1686, 1932.
30. Hirst, J. M.: An Automatic Volumetric Spore Trap, *Ann. Appl. Biol.* 39: 257, 1952.
31. Jones, M. D.: Time of Day of Pollen Shedding of Some Hay Fever Plants, *J. ALLERGY* 23: 247, 1952.
32. Hawes, R. C., Small, W. S., and Miller, H.: An Apparatus for Determining the Pollen Content of Air and Notes on Pollen Survey Methods, *J. ALLERGY* 13: 474, 1942.
33. Johnson, C. G.: The Comparison of Suction Trap, Sticky Trap and Tow-net for the Quantitative Sampling of Small Airborne Insects, *Ann. Appl. Biol.* 37: 268, 1950.
34. Shapiro, R. S., and Rooks, R.: The Accuracy of the Reported Ragweed Pollen Count as a Measure of the Actual Pollen Exposure of Individuals in That Community, *J. ALLERGY* 22: 450, 1951.
35. Perkins, W. A.: The Rotorod Sampler, Second Semiannual Report, CML 186, Aerosol Laboratory, Stanford University, 1957.
36. Gregory, P. H.: Deposition of Air-borne Lycopodium Spores on Cylinders, *Ann. Appl. Biol.* 38: 357, 1951.