Vertical Spore Concentrations of Three Wheat Pathogens Above a Wheat Field

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Cooperative investigations of the Plant Science Research Division, ARS, USDA, and Kansas Agricultural Experiment Station. Contribution No. 547, Department of Plant Pathology and Contribution No. 1134, Division of Biology.

Portion of a Ph.D. thesis submitted to Kansas State University by the senior author.

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Accepted for publication 5 March 1972.

ABSTRACT

Kramer-Collins volumetric samplers were used to study vertical dispersal and dissemination of urediospores of *Puccinia recondita* and *P. graminis*, and conidia of *Erysiphe graminis*, above a source area in 1969 and 1970. Air within the canopy and at 1, 3, and 6 m above ground level was sampled to measure the hourly and daily variations in spore concentrations which were then related to variations in meteorological data obtained in the same field. Considerable daily and hourly variation in spore concentrations of the three species occurred within and above the wheat canopy. Circadian patterns with distinct diurnal maxima were noted in both years. However, variation in meteorological factors could cause rapid changes in spore concentrations, with peaks occurring any time during the day or night. Changes in wind velocity or turbulence accounted for most of the peaks observed in hourly spore concentrations. Higher wind velocities were required to dislodge spores when the foliage was wet or when pustules were located lower in the canopy. When spore concentrations and sampling height were plotted on logarithmic scales, the three species exhibited distinctly different spore profiles. These differences were attributed to exogenous *P. graminis* and to endogenous and exogenous *P. recondita* urediospores being trapped above the canopy, whereas the infected wheat canopy was the source of the *E. graminis* conidia. Profiles of spore concentrations at different heights can be used to distinguish between endogenous, exogenous, and mixed inoculum sources, and aid in positioning of samplers used in epidemiological studies.

Phytopathology 63:211-218

Additional key words: aerobiology, epidemiology.

Attempts to forecast epidemic development of powdery mildew and stem rust and leaf rust on wheat (*Triticum aestivum* L.) have shown the need for detailed information on the aerobiology of the causal organisms *Erysiphe graminis* DC., *Puccinia graminis* Pers. f. sp. *tritici* Eriks. & E. Henn., and *Puccinia recondita* Rob. ex Desm. f. sp. *tritici*, respectively. The seasonal occurrence of urediospores and their relationship to local cereal-rust epidemics have been well established (2, 16, 17). However, because silicone-coated glass slides and rods exposed a few centimeters above the growing crop have been used in most epidemiological studies of urediospore concentration and movement, these studies have been largely qualitative rather than quantitative (2, 16).

Several workers studying long-distance movement of spores have attempted to measure vertical changes in spore concentration above 500 m (10), but few have sampled the air nearer the ground or within the canopy. Gregory (6) states that vertical spore concentrations are relatively uniform up to 1 km in a stable air mass, but Hirst & Hurst (10) have reported deviations up to 500 m. Over source areas, where concentrations are generally higher than over areas without a host crop, spore concentrations decrease logarithmically with increasing altitude (5).

Concentrations of airborne urediospores over a source area also vary with time of day, with maximum concentrations generally occurring near midday. However, that may vary depending on the different atmospheric processes that are interrelated and affect release of spores into the air. The production of spores may also affect hourly concentrations of airborne spores, but it is not known when spores are produced in the field.

Hirst & Hurst (10) and others (1, 7, 8) reported a single early afternoon peak in airborne urediospores. Commack (3) reported a daily peak in *Puccinia polysora* Undw. urediospores in midmorning in a dry season and in early afternoon in a wet season. Pady et al. (15) first reported the early evening or nocturnal peak in addition to the diurnal peak observed in the concentration of airborne urediospores, although data of others (1) indicated that such peaks existed. Time of the season also strongly influences spore concentrations over a source area.

Maximum production of *P. recondita* urediospores in a wheat field occurs between heading and dough stages of the wheat plants. As the infected leaves senesce, the concentration of urediospores in the canopy decreases rapidly. Maximum production of *P. graminis* urediospores occurs several weeks later than that of *P. recondita* urediospores. Sporulating *P. recondita* uredia are first observed near Manhattan, Kans. ca. 25 April; and *P. graminis*, ca. 1 June.

Severe rust epidemics, often contributing to the withdrawal of a cultivar from production, are quite common in all the main wheat growing areas of the world. Evidence of infection of large acreages of wheat from a geographically remote inoculum source is fairly well documented. Mehta (14) reported the spread of *P. graminis* from mountain regions of India to the plains area by wind-blown inoculum. Movement of urediospores from Mexico to Canada via the Upper Mississippi River Valley was investigated by Asai (1). Infection of wheat on the British Isles by inoculum carried across the English Channel from the European Continent has been documented by Hirst & Hurst (10). McEwan (13) concluded that New Zealand cultivars were infected by urediospores carried from Australia by wind because it is improbable that simultaneous mutations would occur in both New Zealand and Australia to give rise to a new physiological race of *P. graminis*.

Because airborne urediospores are of major importance in the rapid dissemination of cereal rust pathogens, we used volumetric samplers to measure the vertical dispersal and dissemination of urediospores above a source area. Air within the canopy and at 1, 3, and 6 m above ground level was sampled to measure the hourly variations in spore concentrations which were then related to variations in meteorological data obtained in the same field. Knowledge of the circadian patterns and the meteorological factors affecting urediospore dispersal will be of major importance in any attempt to issue long range disease forecasts.

MATERIALS AND METHODS.–Kramer-Collins volumetric samplers (11) were used to sample air at four heights above ground level between 20 May and 20 June in 1969 and 1970. Samplers were situated on two towers, with one 300 m downwind (NE) from the other. One sampler on each tower was raised as the wheat increased in height to keep the sampling orifice ca. 15 cm above the canopy (1 m). Two additional samplers were operated 3 and 6 m above ground level on each tower. A fourth sampler was located in the canopy at the base of each tower. It was raised periodically to keep the sampling orifice at the same level as the majority of the sporulating *P. recondita* uredia. Rotary wind vanes were used to keep sampling orifices pointing into the wind and to keep precipitation out of the samplers (12).

In 1969, the towers were located in a three-acre field of Bison (C.I. 12518) wheat planted on the Rocky Ford experimental plots northeast of Manhattan, Kansas. The south tower was 30 m inside the plot, ca. 80 m north of scattered 6- to 12-m trees. Each sampler was timed individually, and all four samplers on a tower were turned off and on within ± 2 min.

In 1970 the towers were moved to a 15-acre field of Shawnee (C.I. 14157) wheat on the Ashland agronomy farm south of Manhattan. The Kramer-Collins samplers were modified by replacement of all spring-wound clock motors with one revolution/hr (rph) 110-v AC motors. The motors were timed to advance the slides on the hour. A single 1-rph 110-v AC motor operated a microswitch that turned the four samplers on a tower off and on simultaneously. Samplers on the north tower were turned off and on within ± 5 sec of those on the south tower.

Instruments used to obtain meteorological data were 6 m from the base of one of the towers. Wind tunnel psychrometers operated continuously by 110-v AC motors were used to obtain wet bulb-dry bulb temperature measurements for relative humidity determinations in the canopy and at 1 m above ground level. Occurrence of free moisture was determined by visual observations, dew records, and National Weather Service records (18). Anemometers were used to measure the along-wind component, across-wind component, and vertical-wind (turbulence) component. A record of the three wind components was made on separate strip chart recorders every 4 sec. We calculated turbulence values by obtaining the absolute value of the difference between the maximum and minimum vertical wind movement during an hour. Observations of disease severity, crop growth stage, and location of diseased tissue on the wheat plants were made several times a week.

Exposed slides were examined under a microscope, and the number of spores of each species deposited per hourly band were counted (11). Hourly spore data were recorded as spores trapped per 0.1 m^3 of air sampled. Daily spore data were recorded as spores trapped per m^3 of air sampled. Logarithmic scales were used to plot spore concentrations in Fig. 1-6. Hourly spore and meteorological data were analyzed using regression techniques and analysis of variance.

RESULTS.–*Daily concentrations of E. graminis conidia, P. graminis, and P. recondita urediospores recorded in 1969 and 1970.*–Considerable daily variation in spore concentration was evident in both years (Fig. 1). Cool temperatures and humid nights in early May 1969 contributed to a heavy outbreak of powdery mildew on rank Bison wheat. By 20 May, when sampling started, powdery mildew severities of 40% were observed, and concentration of airborne conidia was at a maximum, with conidia being dislodged by 2-3 mph winds. The decrease in conidia concentration on 22 May 1969, even though disease severity was increasing, is attributed to low wind velocities and wet plant surfaces.

Maximum powdery mildew severity (60%) was observed on 24 May, with many pustules on flag leaves of the wheat plants. The decrease in conidia trapped after 27 May was due to the warm temperatures of 25-28 May which were unfavorable for continued pustule and conidium development. By 29 May, all powdery mildew pustules were on lower portions of the tiller, 10-12 cm below the sampling orifice.

Major increases and decreases in *P. recondita* and *P. graminis* urediospores trapped per day were correlated with corresponding increases or decreases in wind velocity, temperature, or both, and by the occurrence of rain or dew. As average daily temperatures increased, disease development and

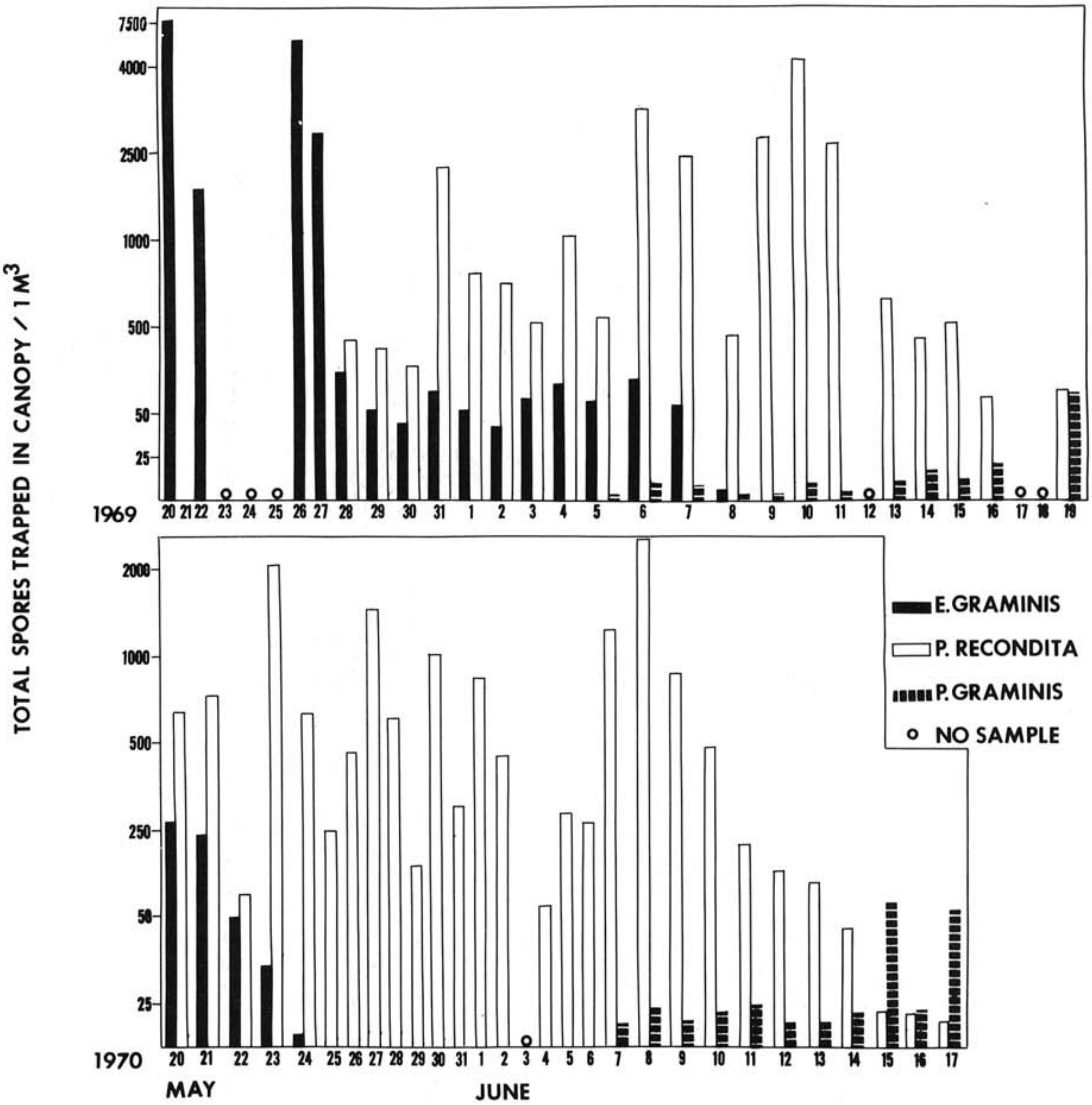

Fig. 1. Daily spore concentrations of *Puccinia graminis*, *Puccinia recondita*, and *Erysiphe graminis* trapped in the canopy during 1969 and 1970.

sporulation of uredia increased. Daily spore concentrations of *P. recondita* in the canopy increased 4-fold on 31 May 1969 as wind velocity and turbulence increased prior to the passage of a cold front. A decrease in temperature on 1 June coupled with a slight decrease in turbulence decreased spore concentration 60%. The 5-fold increase in *P. recondita* spore concentration on 6 June is attributed to a corresponding increase in temperature and turbulence.

The sharp decrease in spore concentration on 8 June probably resulted from reduced spore production when maximum temperature dropped 12 C. Also, a rain shower kept the plant surfaces wet, and spores precipitated out of the air mass so exogenous spores did not influence the urediospore concentration in the canopy. During the same period, turbulence was comparable to that on preceding days. As temperature increased significantly on 9 June, urediospore concentrations increased rapidly, apparently due to increased spore production. The decline in *P. recondita* urediospore concentration after 11 June coincided with senescence of the flag leaves, which bore the sporulating uredia, and with a rain 12 June, which precipitated exogenous spores from the atmosphere. For the next several days, winds were from the north or northeast blowing over areas with very small acreages of wheat.

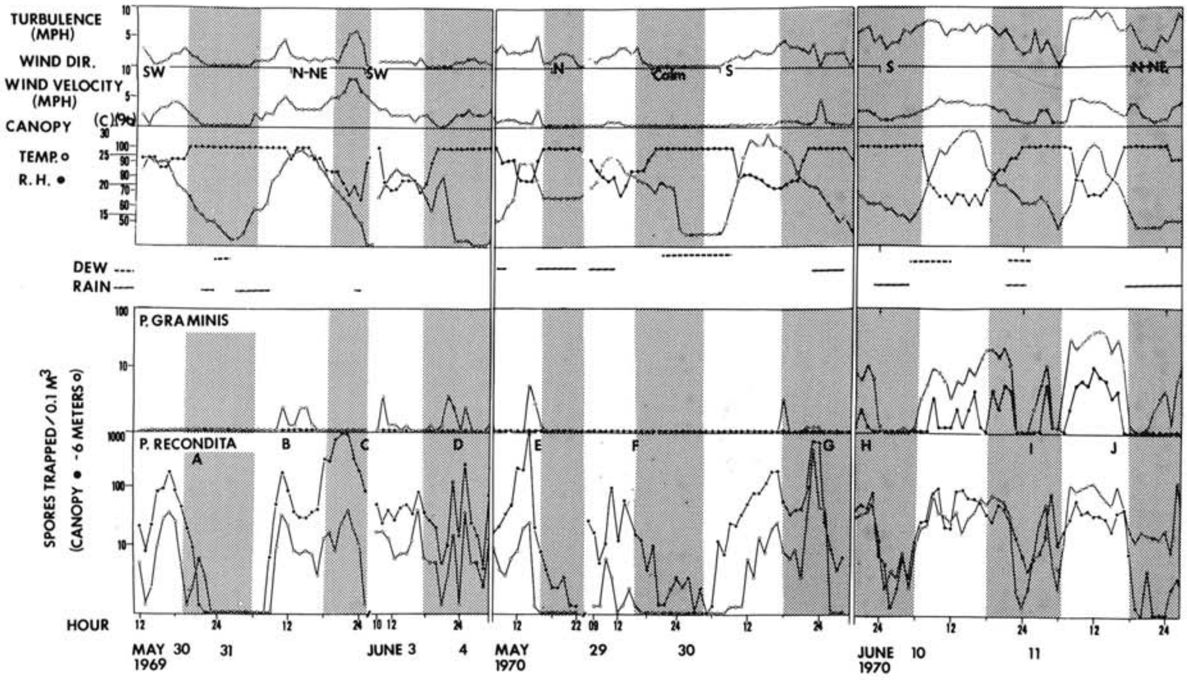

Fig. 2. Hourly concentration of *Puccinia recondita* and *Puccinia graminis* urediospores trapped in the canopy and at 6 m above ground level, and meteorological data obtained 1 m above ground level 30 May to 4 June 1969, 28 May to 1 June, and 9 June to 11 June 1970.

In contrast to 1969, relatively few *E. graminis* conidia were trapped in 1970 when lower disease severities occurred, perhaps because of less rank crop growth, changes in meteorological factors, or genetic resistance to *E. graminis* in the cultivar planted in 1970. In contrast to 1969, *P. recondita* urediospores were trapped in substantial numbers the 1st day of sampling in 1970. The increased spore concentrations trapped 23 May 1970 resulted from increased wind velocity prior to a rain and to an increase in sporulating uredia.

One to 3 June were extremely cool, with intermittent rain showers keeping the canopy wet most of the time. Turbulence was high during this period and accounted for 40% of the variation ($r^2 = .4$) in spore concentrations; 4-7 June were relatively calm, with only a trace of rain on 4 June. After this period of low temperatures and northwest winds an increase in temperature, disease severity, and wind velocity resulted in higher urediospore concentrations on 7 and 8 June. Starting 9 June, a week of rainy weather and loss of leaves bearing sporulating uredia reduced daily urediospore concentrations to a minimum.

Hourly variation in E. graminis conidia trapped in 1969 and 1970.—Variation in numbers of *E. graminis* conidia trapped in 1969 and 1970 follow patterns of increasing and decreasing wind velocity and turbulence. Peaks in conidia concentration were observed as wind velocity, and turbulence increased prior to the occurrence of rain showers. Sharp declines in conidia concentrations were observed during and after rain showers that washed the conidia from the air.

Hourly concentration of P. recondita and P. graminis urediospores in 1969.—Increases in wind velocity and turbulence resulted in a peak concentration of *P. recondita* urediospores at 1600 hr on 30 May (Fig. 2-A). The second peak at 2200 hr at 6 m was measured prior to a light rain shower. Lower temperatures and a light rain shower during a calm period kept wheat plants wet, and reduced spore concentrations to zero until wind velocity increased at 0600 on 31 May. As plants dried and wind velocities increased, spore concentrations also increased (Fig. 2-B). Higher wind velocities and increased turbulence just prior to the passage of a cold front through the area caused a peak at 2200 hr (Fig. 2-C). Wind gusts from 1-15 mph were recorded from 2200 to 2400 on 3 June (Fig. 2-D).

The first *P. graminis* urediospore was trapped at 6 m on 28 May after 3 days of moderate south-southwest winds. The first urediospore was trapped in the canopy on 5 June, and the first *P. graminis* uredium was observed in the plot on 6 June 1969, 11 days after the first urediospore was trapped at 6 m.

Repeated fluctuations in spore concentrations between 0700 and 0800 hr appear to be related primarily to the samplers being out of operation for servicing a few minutes during each hour. Care must be exercised in reporting data taken with any sampling device when the environment sampled has been disturbed.

There was little difference between spore concentrations measured at 6 m and in the canopy as the wheat matured. The plot was not the source of most of the *P. recondita* urediospores being trapped after 17 June 1969 because no sporulating uredia were observed in the plots.

Hourly variation in P. recondita and P. graminis urediospore concentrations in 1970.—The peak in *P. recondita* urediospores trapped at 1400 on 28 May (Fig. 2-E) was associated with rapid increases in wind velocity and turbulence the hour preceding passage of a cold front. The decrease in spore concentration at 1500 hr coincided with temperature and wind velocity decreases. The decrease in spores trapped at 6 m was due to the effect of rain which precipitated spores out of the atmosphere. The first *P. graminis* urediospores of the season were trapped at 6 m just before a cold front passed.

Peak spore concentrations at 1300 and 1500 on 29 May (Fig. 2-F) occurred immediately after a rain shower ended. Wind velocities increased at 1300 hr, decreased to zero at 1400, then increased by 1500 hr. The decrease at 1400 was probably caused by moisture still on the plants; therefore, with low wind velocities, few spores were dislodged. Also, greater wind velocities would be required to dislodge the urediospores from leaves lower in the plant canopy.

The large increase in spore concentration at 2300 on 30 May resulted from rapid increases in wind velocity and turbulence just before a rain storm moved through the area (Fig. 2-G). Wind velocity increased from 2 to 9 mph at 0045 hr and the rain commenced at 0115 on 31 May.

The first *P. graminis* uredium was observed in the field on 5 June, 9 days after the first urediospores had been trapped at 6 m. Urediospores were first trapped in the canopy on 7 June, but more urediospores were usually trapped at 6 m than in the canopy. Increased turbulence prior to a rain caused a small peak at 2300 on 9 June (Fig. 2-H). The decrease in spore concentration at 2400 hr was probably due to rain precipitating spores from the atmosphere.

After a light rain shower (0.03 inches) at 2300 on 10 June (Fig. 2-I), rapid fluctuations in wind velocity and turbulence caused peaks in spore concentrations at 0400 on 11 June. Wind velocity and turbulence decreased for 3 hr, then increased sharply, resulting in an increase in spore concentration at 0800 on 11 June. Just prior to a rain shower at 1800 on 11 June (Fig. 2-J), the wind direction shifted from southeast to northeast and the number of spores trapped decreased sharply while the wind blew across areas with very small acreages of diseased wheat. The change in wind direction resulted in fewer *P. graminis* urediospores being trapped at 6 m compared to the change in concentration of *P. recondita* urediospores trapped at 6 m. This would indicate that the main source of the *P. graminis* urediospores was south of Manhattan, Kans., and not the local plot, as the concentration of *P. graminis*

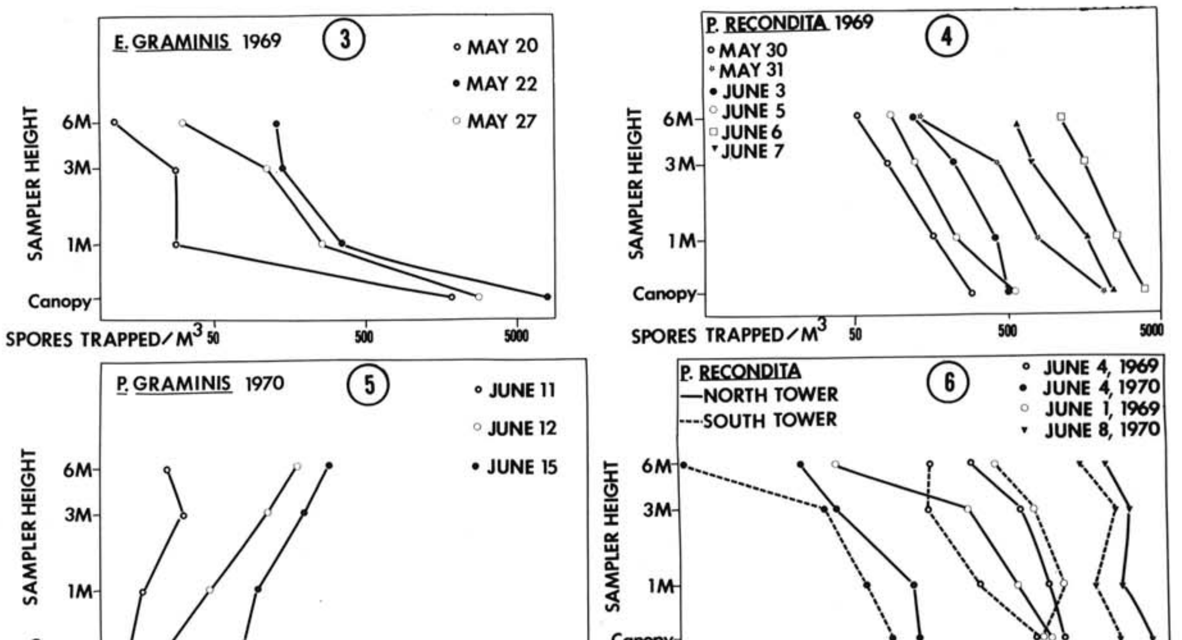

Fig. 3-6. 3) Profiles of the daily spore concentration of *Erysiphe graminis* conidia trapped in 1969. **4)** Profiles of the daily spore concentration of *Puccinia recondita* urediospores trapped in 1969. **5)** Profiles of the daily spore concentration of *Puccinia graminis* urediospores trapped in 1970. **6)** Comparison of profiles of daily spore concentration of *Puccinia recondita* urediospores trapped on different towers in 1969.

urediospores increased again as the wind shifted back to the southeast at 0200 on 12 June. However, except for a peak at 0200 hr, the concentration of *P. recondita* urediospores did not change.

In both 1969 and 1970, *P. graminis* urediospore concentrations at 6 m exceeded urediospore concentrations in the canopy, whereas the opposite was true for *P. recondita* urediospore concentrations.

Profiles of spore concentrations in 1969 and 1970.—The three species exhibit distinctly different spore profiles when sampler height and spore concentration were plotted on a logarithmic scale. Concentration of *E. graminis* conidia decreases rapidly between the canopy and 1 m; then more gradual decreases occur from 1 m to 3 m, and from 3 m to 6 m (Fig. 3). Spore concentration of *P. recondita* also decreased with increased height (Fig. 4); however, the decrease was usually logarithmic and more gradual than the decline for *E. graminis*. The *P. graminis* profile was in direct contrast, tending to increase logarithmically with increased sampling height (Fig. 5). Preliminary analysis of meteorological variables do not explain the differences in the slope or form of either *E. graminis* conidia profiles for 20, 22, and 27 May 1969 (Fig. 3) or *P. graminis* urediospore profiles for 11, 12, and 15 June 1970 (Fig. 5).

P. recondita urediospore profiles varied only slightly in form or slope during 1969 (Fig. 4) or 1970. Changes in either disease severity estimates or average hourly wind velocities for a day account for the increase in spore concentrations and the positioning of the daily profile on the graph. Very high wind velocities like those on 31 May would dislodge mature urediospores and cause spore concentrations to be obtained from low severities that are comparable to those measured on days with lower wind velocities but when disease severities are higher (7 June).

P. recondita profiles for 1969 (Fig. 6) varied considerably for the two locations, indicating that the obstructions a few meters south of the upwind tower increased turbulence. The decrease in spore concentrations at 6 m on the upwind tower was not as rapid as the decrease at 6 m on the downwind tower when the wind was from the south or southwest. The shape and form of spore concentration profiles for the two towers in 1970, when there were no upwind obstructions, are very similar.

Ratios of daily spore concentrations at different sampling heights.—When the wheat field was the source of spores, spore concentrations within the canopy were greater than those at 1 or 6 m. Ratios were calculated by division of the spore concentration at the upper elevation by the spore concentration at the lower elevation. The ratio of spore concentration at 1 and 6 m above ground level to those within the canopy varied with the different fungal species. Ratios for *P. graminis* were, with four exceptions in 1969, between 1.10 and 8.18, indicating that more urediospores were trapped above the canopy than within the canopy (Table 1). Exceptions in 1969 occur on days with north-northwest winds. Several 10-m^2 areas on the northwest edge of the plot, 500 m northwest of the northeast tower, had been inoculated with *P. graminis* urediospores earlier in the season. Those infected areas acted as a source only with north-northwest winds; otherwise, the plot was not the major source for the urediospores trapped. Generally, more *P. graminis* urediospores were trapped at 6 m above ground level than at 1 m.

Since only trace severities of powdery mildew were observed in a 4- to 5-km radius of the plot, it was assumed that the canopy was the source for the *E. graminis* conidia trapped both years. Ratios of conidia concentrations at 1 and 6 m to conidia concentrations within the canopy ranged from 0.015 to 0.092 and from 0.005 to 0.016, respectively, and support the assumption that the canopy was the source of the spores trapped (Table 2).

Ratios for *P. recondita* urediospore concentrations at 1 and 6 m to urediospore concentrations within the canopy ranged from 0.16 to 0.80 and from 0.043 to 0.55, respectively (Table 3).

DISCUSSION.—A cold front is defined meteorologically as the boundary along which warm air is replaced by cold air (4). An air mass that is warmer than the surrounding air has bouyancy and moves upward while a cooler air mass takes its place. A thermally caused upward movement of spore-laden air occurs quickly over a small area, but the air mass usually subsides slowly over larger geographical areas. The fast-moving cold front that passed through the sampling site at 0100 on 31 May 1970, was accompanied by heavy rains preceded by increased surface and atmospheric wind velocities and turbulence. Surface turbulence increases dissemination of the spores into the atmosphere, and greater atmospheric turbulence tends to hold and transport spores. Therefore, turbulence becomes the major element of vertical spore movement. Correlation coefficients for turbulence with spore concentrations at 6 m were generally higher than those for other meteorological variables.

Spore concentrations over a source area are greatest near the ground, and decrease with altitude. A similar phenomenon occurs on a horizontal plane from a source area (16). This can be demonstrated by releasing smoke within the canopy or a few meters above the ground level. In a mild wind, the smoke tends to rise and diffuse into the surrounding air mass as it moves away from the source, but in a stronger wind (e.g., 20 mph) it tends to continue in a horizontal plane, with no immediate rise or mixing with the surrounding air. The expansion of an air mass due to heating or increase in altitude and turbulent mixing within the air mass dilutes the spore concentration of the air mass.

Although considerable daily and hourly variation was observed in spore concentrations trapped within and above the wheat canopy, circadian patterns with distinct peaks were noted in both years. Rapid changes in spore concentrations occurred at all times

TABLE 1. Ratios of *Puccinia graminis* urediospore concentrations between 1 m and the canopy (1:C), 6 m and the canopy (6:C), and 6 and 1 m (6:1) with average wind velocity, wind direction, and disease severity estimates in 1969

June	Ratios between			Wind velocity	Wind direction	Stem rust severity (%)
	1:C	6:C	6:1			
9	5.00	7.00	1.40	2.1	SW	Trace
10	4.21	3.18	0.82	4.3	SW	Trace
11	0.60	1.10	1.83	3.2	SW–NW	1
13	0.85	0.40	0.47	2.5	NE–NW	1

TABLE 2. Ratios of *Erysiphe graminis* conidia concentrations between 1 m and the canopy (1:C), 6 m and the canopy (6:C), and 6 and 1 m (6:1) with average wind velocity, wind direction, and disease severity estimates in 1969

May	Ratios between			Wind velocity	Wind direction	Powdery mildew severity (%)
	1:C	6:C	6:1			
20	0.043	0.016	0.378	2.8	E	40
22	0.015	0.006	0.400	1.4	NE	45
26	0.055	0.005	0.083	2.2	SW	60
27	0.092	0.011	0.122	3.0	SW	60

TABLE 3. Ratios of *Puccinia recondita* urediospore concentrations between 1 m and the canopy (1:C), 6 m and the canopy (6:C), and 6 and 1 m (6:1) with average wind velocity, wind direction, and disease severity estimates in 1969

June	Ratios between			Wind velocity	Wind direction	Leaf rust severity (%)
	1:C	6:C	6:1			
6	0.658	0.289	0.439	3.6	SW	40
7	0.669	0.234	0.350	3.9	NE	50
8	0.520	0.150	0.289	2.3	NE	50
9	0.324	0.047	0.145	2.1	SW	60

of the day or night during the sampling period. The time of maximum spore concentration varied with the effect of the meteorological factors present during a particular hour or day.

Regression analysis of data for each year indicated that variations in temperature and relative humidity within the canopy explained more of the variation in hourly spore concentrations than was explained by variations in temperature and relative humidity occurring 1 m above ground level.

Coefficients of determination for selected hours and days (Fig. 2) show that from 30 to 80% of the variation in spore concentrations in the canopy could be explained by either wind velocity or turbulence. Coefficients of determination also indicated little difference in amount of variation in spore concentration in the canopy that could be explained by variation in either wind velocity or turbulence.

Correlations of fluctuation in spore concentration with fluctuation in wind velocity and turbulence indicated these variables were two of the most important meteorological factors influencing hourly changes in spore concentrations in 1969 and 1970. Hirst (9) concluded from data on urediospore liberation in a wind tunnel that urediospores were abscissed some time prior to actual liberation and were available for dispersal as a floccose powder of detached spores. His data suggested that peaks in spore concentrations resulted from changes in wind velocity, temperature, or relative humidity.

Changes in wind velocity or turbulence accounted for most of the hourly peaks observed in spore concentration during 1969 and 1970. When the canopy was wet, higher wind velocities were required to dislodge spores in the canopy than when the foliage was dry. Also, if spore-bearing tissue was located lower in the canopy, higher wind velocities were required for spore dispersal.

Peaks in spore concentration generally occurred as plant surfaces dried in midmorning. The longer the plant surfaces remained wet, the later in the day the peak spore concentration occurred. Peaks in spore concentration occurred as wind velocities and turbulence increased prior to a rain shower or passage of a cold front, and not as a result of the impact of rain droplets on the spore-bearing tissue. With air sampling for the hourly bands beginning on the hour (e.g., 0100, 31 May 1970) it can be seen that the peak in spore concentration at 2400 on 30 May 1970 (Fig. 2-G) coincided with increased wind velocity and turbulence before the rain, and was not caused by the impact of rain droplets on the canopy, as the rain did not start until 0115 hr. It usually took a few minutes for a rain shower to precipitate the spores from the atmosphere, but a much shorter time was required for a decrease in spore concentration within the canopy. If a rain shower was not preceded by increased wind velocities, like most of the rains occurring in the Great Plains area, then the impact of rain droplets would affect the concentrations of spores being dislodged from spore-bearing tissue.

Extended periods of rainy weather in 1970, which kept plant surfaces wet, reduced the total spore concentration in 1970 as compared to total spore concentration in 1969, although approximately equal disease severity estimates were made in both years. Spore production may have been influenced by genetic differences in the wheat cultivars.

Although disease severity estimates of 20-30% on flag leaves were observed in mid-May for powdery mildew and for leaf rust in early June, the ratios for *P. recondita* urediospores were much higher than were corresponding ratios for *E. graminis* conidia concentrations, even though wind velocities during the different time periods were approximately equal. Therefore, ratios of spore concentrations indicate that in addition to the *P. recondita* urediospores originating in the canopy, exogenous urediospores were also trapped above the canopy.

Data in Fig. 4, 5, and 6 show that care should be exercised in positioning a sampler when studying endogenous or exogenous inoculum sources. The sampler should be located several meters above ground level to trap the first spores being transported into an area by an air mass.

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