Horizontal Dispersal of Urediospores of *Puccinia recondita* f. sp. *tritici* and *P. graminis* f. sp. *tritici* from a Source Plot of Wheat

M. G. Eversmeyer and C. L. Kramer

Research plant pathologist, USDA, SEA, AR, Department of Plant Pathology, and professor, Division of Biology, respectively, Kansas State University, Manhattan 66506.

Cooperative investigations of the U.S. Department of Agriculture, Science and Education Administration, Agricultural Research, and the Kansas Agricultural Experiment Station. Contribution 79-240-J of the Kansas Agricultural Experiment Station.

Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture, and does not imply approval to the exclusion of other products that also may be suitable.

Accepted for publication 9 January 1980.

ABSTRACT

EVERSMEYER, M. G., and C. L. KRAMER. 1980. Horizontal dispersal of urediospores of *Puccinia recondita* f. sp. *tritici* and *P. graminis* f. sp. *tritici* from a source plot of wheat. Phytopathology 70:683-685.

Kramer-Collins volumetric samplers were used to sample air 6 m above ground level to measure downwind dispersal of *Puccinia recondita* and *P. graminis* urediospores from a wheat plot. The rate of decrease in the average numbers of *P. recondita* and *P. graminis* urediospores trapped per cubic meter of air sampled in the wheat canopy and at 6 m above ground level 60, 120, and 180 m downwind from the wheat plot was calculated by regression analysis. Beta coefficients (b) of urediospore dispersal per meter downwind were calculated by using the $\log_{10}$ of the spore concentration within the canopy as the source concentration. Beta coefficients of −0.006 for *P. recondita* and −0.004 for *P. graminis* were calculated. Spore-trapping stations in most epidemiological studies have been located just above the canopy or 1 m above ground level. Beta coefficients of −0.001 for *P. recondita* and −0.002 for *P. graminis* were calculated by using the $\log_{10}$ of the spore concentration at 1 m as the source concentration. Virtual point source strengths were calculated and regression analysis resulted in r^2 values of 0.88 for *P. recondita* and 0.87 for *P. graminis*. Constants for the slope of the regression lines (b) were −0.017 and −0.015, respectively. Downwind spore concentrations predicted by the use of virtual point source strengths were not significantly different than measured downwind spore concentrations.

Additional key words: aerobiology, airspora, epidemiology, *Triticum aestivum*.

Given favorable environments and compatible host:parasite interactions, rapid development of a cereal rust epidemic over large areas depends in part on the effectiveness of urediospore dispersion. Hirst and Hurst (6) and Gregory (5), studying long-range transport of fungal spores, attempted to measure vertical changes in spore concentrations above 500 m. Gregory (4) stated that vertical spore concentrations are relatively uniform up to 1 km in a stable air mass. Others (1,2) have reported that spore concentrations decrease logarithmically with increasing altitude over source areas where spore concentrations are higher than those over areas without a host crop.

In previous papers (1,2), we reported that numbers of urediospores of *Puccinia graminis* Pers. f.sp. *tritici* Eriks. and E. Henn. and *P. recondita* Rob. ex Desm. f.sp. *tritici* trapped within a wheat canopy indicate the number of spores being released from a point source. Spore concentrations of *P. recondita* 15–25 cm above the canopy were less than 10% of the concentrations within the canopy, when most of the sporulating tissue was below the flag leaf. At 6 m above ground level, urediospore concentrations were less than 2% of the concentrations observed in the canopy.

These studies indicate that a very small percentage of the urediospores produced on the host tissue actually escape the canopy, become airborne, and are effectively dispersed from the source area. The percentage of urediospores that escape the canopy and are trapped at 1 m above the canopy depends largely on the location of the sporulating tissue in the canopy. Meteorological factors also influence the percentage of urediospores that become airborne from a source area. Within a 24-hr period, concentrations of airborne spores fluctuate with wind velocity, turbulence, dew, rain, and storm fronts, as well as periodicity in spore production (1,3). Roelfs (10) found that an average of 3 and 6% of the initial number of *P. graminis* and *P. recondita* urediospores, respectively, that were trapped at 15 cm above a source would be trapped at the same height 100 m downwind.

Several theories on spore dispersal have been used to describe actual dispersal gradients horizontally from a natural source (3,4). Urediospore dispersal gradients calculated from physical laws of particle movement assume constant mass and shape of spores, constant wind velocity, and no wind turbulence during the sampling period. These characteristics of the spore and of the meteorological factors vary during a sampling period. Roelfs (10) found that actual horizontal spore dispersal gradients 1 m above ground level compared favorably with theoretical models for the prediction of urediospore movement.

In the present study we estimated downwind dispersal of urediospores from a source plot of wheat. Volumetric spore samplers were used to sample spore concentrations within and 15–25 cm above the wheat canopy and at 6 m above ground level downwind of a source plot.

MATERIALS AND METHODS

A 100 × 100-m plot of winter wheat (*Triticum aestivum* L. 'Eagle') at the Ashland Agronomy farm near Manhattan, KS served as a urediospore source. The area surrounding the plot for at least 500 m was planted to row crops. During the sampling period 25 May–25 June, the top of the row crop canopy was below the top of the wheat canopy (80 cm) for at least 300 m on all sides of the plot. The closest source of exogenous urediospores was ~ 0.6 km east of the test area. The closest upwind source of urediospores was 1 km south of the wheat plot. The plot was not artificially inoculated with either *P. recondita* or *P. graminis* urediospores.

Three spore trapping stations were located on towers 6 m above ground level at 60-m intervals downwind of the leeward edge of the source area. A fourth tower with a spore trapping station at 6 m was located 3 m inside the leeward edge of the plot with a second trapping station (referred to as the 1-m sampler) located 1 m above ground level. The 1-m sampler was ~ 15–25 cm above the wheat canopy during the sampling period. An additional sampling station, referred to as the canopy sampler, was located in the wheat

canopy near the base of the tower. The position of the canopy sampler orifice was adjusted at intervals throughout the sampling period to the level of the majority of the sporulating leaf rust pustules.

Kramer-Collins (K-C) (7) volumetric samplers were mounted on 25 × 25-cm platforms which were raised and lowered daily for servicing by a pulley system attached to a cross arm of the tower. Guide wires attached to the platform prevented the samplers from swinging freely in the wind. Rotary intake tubes (8) were used on the samplers to keep sampling orifices pointing into the wind and to keep out precipitation.

Instruments used to obtain meteorological data were 10 m from the tower in the wheat canopy or at 1 m above ground level. 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 and dew records. Precipitation amounts were obtained from standard rain gauges. UVW anemometers were used to measure the along-wind, across-wind, and vertical-wind (turbulence) components. 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 1 hr. Observations of disease severity, crop growth stage, and location of diseased tissue in the wheat plants were made several times each week.

Exposed slides from the samplers were examined under a microscope and the numbers of *P. recondita* and *P. graminis* urediospores collected per hourly band were recorded. All samplers were adjusted to sample simultaneously four times an hour for a total of 12 min/hr at a flow rate of 22.7 L/min. Hourly spore and meteorological data were analyzed by standard regression techniques and analysis of variance.

RESULTS

Hourly concentrations of *P. recondita* and *P. graminis* urediospores measured by volumetric traps within, above, and downwind of the source area were obtained. Analyses were based upon data taken during a 6-day sampling period, 1–6 June, before a 3-day rainstorm (12.5 cm) on 7–9 June, and a 6-day sampling period, 11–16 June, following passage of the storm front to eliminate spurious effects caused by varying disease severities during the rest of the sampling season. Wind speeds before and after passage of the storm front averaged approximately 3 m/sec. Leaf rust severity on the flag leaf was estimated at 40% (according to the modified Cobb scale [9]) during the 1–6 June sampling period. Stem rust severity was estimated at 2% on flag leaves and 1% on culms. Ratios of the average number of *P. recondita* urediospores trapped at various heights above the canopy (C) were: 6 m:1 m = 0.48; 6 m:C = 0.18; and 1 m:C = 0.37, which were similar to those reported in an earlier study (2).

Average concentrations of *P. graminis* and *P. recondita* urediospores per cubic meter of air sampled in the wheat canopy, 1 m above the canopy, and 6 m above ground level at 60 m, 120 m, and 180 m north of the wheat plot for a 6-day period prior to and a 6-day period after passage of a storm front on 7 June are shown in Table 1.

Analyses of variance were used on the spore concentration data for each rust species to determine if a significant difference existed in the spore concentrations at the various horizontal distances. The variance ratio, F, was obtained for the daily spore concentration as well as for the hourly concentrations. Significant differences ($P = 0.05$) were found in all the downwind spore concentrations. Significant differences were not found between the various horizontal sampling stations when the plot was not the major source of urediospores (11–16 June).

Urediospore dispersal gradients downwind of the source plot were calculated for each hour and for the average spore concentration of each species. The rate of decrease in the log of numbers of urediospores trapped per cubic meter of air per meter of distance downwind from the source is given by b in the regression of the form $\log \hat{y} = a + b X$. When the $\log_{10}$ of the number of urediospores trapped in the canopy was used for the source (X_0) in the regression analyses, the number of *P. recondita* and *P. graminis* urediospores trapped decreased by −0.006 and −0.004, respectively, for each meter of distance from the source. Coefficients of determination (r^2) of 0.41 and 0.29 were obtained for *P. recondita* and *P. graminis,* respectively. Since in most epidemiological studies the spore-trapping stations are located just above the canopy, we analyzed the data replacing the canopy spore concentrations with spore concentrations at 1 m in the regression analysis. Beta coefficients (b) of −0.001 and −0.002 were obtained for *P. recondita* and *P. graminis,* respectively. Coefficients of determination (r^2) of 0.44 and 0.29 were calculated for *P. recondita* and *P. graminis,* respectively.

During the 6 days following the passage of a frontal system that occurred during the sampling period, winds were predominantly from 270–340° (W-NNW); therefore, during these 6 days, with the exception of only a few hours, the sampling canopy was not the source of *P. graminis* urediospores. Also, the canopy was not the source of *P. recondita* urediospores during these 6 days because almost all of the uredia-bearing leaves became dessicated as a result of exceptionally high temperatures following passage of the storm front.

DISCUSSION

Dispersal of urediospores downwind from a wheat field is a complex phenomenon that does not lend itself to simple mathematical or statistical analysis. Urediospore dispersal gradients were measured in a horizontal plane 6 m above ground downwind from a wheat field to determine the percentage of urediospores trapped within the wheat canopy or a few centimeters above the canopy that would be trapped at various distances downwind. A regression equation was used to predict the number of spores collected at a distance from the source. The relationship can be expressed as $\log Q_x = \log Q_0 + bx$, where Q_x = the predicted spore concentrations at x meters downwind; b = the slope; and x = the distance downwind of the source in meters. The slopes derived from these data are −0.006 for *P. recondita* and −0.004 for *P. graminis* urediospores. If 1,000 *P recondita* urediospores were trapped at the source, then from this formula we would predict that 190 urediospores would be collected at 6 m above ground at 120 m downwind of the source. When the source was considered the $\log_{10}$ of the number of urediospres trapped 15–25 cm above the canopy, then the beta coefficients became −0.001 for *P. recondita* and

TABLE 1. Average number of *Puccinia recondita* f. sp. *tritici* and *P. graminis* f. sp. *tritici* urediospores trapped per cubic meter of air sampled in the canopy, 15–25 cm above canopy, and at 6 m on towers located 60, 120, and 180 m north of a 100 × 100 m urediospore source

	Urediospore concentration									
	1–6 June[a]					11–16 June				
Species	Source canopy	15–25 cm above canopy	60 m	120 m	180 m	Source canopy	15–25 cm above canopy	60 m	120 m	180 m
P. recondita	388	120	169	120	66	13	29	40	41	35
P. graminis	1,065	125	229	155	101	103	142	142	138	101

[a]Source canopy was downwind of sampling stations.

−0.002 for *P. graminis.*

Because the urediospore source was a 10,000 m^2 area, virtual point-source strengths were calculated for all hourly spore concentrations. A virtual point source is that theoretical point upwind of the source area from which particles would have to be released to produce dispersal patterns and concentrations not significantly different from the measured patterns and concentrations at the source area. Source strengths (Q) were calculated as the number of urediospores trapped per cubic meter of air sampled × source area (10,000 m^2). Horizontal dispersion coefficients reported by Slade (11) were used to determine the distance upwind to a virtual point source. Use of virtual point source strengths, calculated from either canopy or 1 m spore concentrations, in regression analyses resulted in r^2 values of 0.88 and 0.87 for *P. recondita* and *P. graminis,* respectively. Constants for the slope (b) of the regression lines were −0.017 and −0.015 for *P. recondita* and *P. graminis,* respectively. These equations enable a more precise and accurate prediction of urediospore movement downwind from a source area than was possible using spore concentrations per cubic meter of air at 1 m or within the source canopy. If 1,000 *P. recondita* urediospores were trapped at the source, then by use of the formula from the virtual point source analysis we predict that 684 urediospores would be collected at 6 m above ground 120 m downwind of the source area. The predicted downwind spore concentrations using the virtual point source formula were not significantly different ($P = 0.05$) than the measured spore concentrations.

Inclusion of the meteorological variables, windspeed in meters per second, turbulence, maximum and minimum temperature, and relative humidity in either linear or multiple regression analysis did not significantly increase the amount of variation in the dependent variable that was explained by spore concentration at the virtual point source alone.

Location of a spore trapping station in relation to spore source is critical to determine if the sample is a measure of endogenous or exogenous spores. Results show that the approximate distance from a source that a sampling station must be located, if it is to be used to measure exogenous spores, can be determined by calculation of virtual point source strengths and distances. Virtual point sources account for the size of the source area and therefore more accurately represent the strength of the source. Therefore, a spore sampling station should be located at least 410 m from a 100 × 100 m source area which produced a virtual point source strength of 1,000 *P. recondita* urediospores if the sample is to be considered a measure of exogenous spores.

LITERATURE CITED

1. EVERSMEYER, M. G., and C. L. KRAMER. 1975. Air-spora above a Kansas wheat field. Phytopathology 65:490-492.
2. EVERSMEYER, M. G., C. L. KRAMER, and J. R. BURLEIGH. 1973. Vertical spore concentrations of three wheat pathogens above a wheat field. Phytopathology 63:211-218.
3. GREGORY, P. H. 1945. The dispersion of airborne spores. Trans. Br. Mycol. Soc. 28:26-72.
4. GREGORY, P. H. 1961. The Microbiology of the Atmosphere. Intersci. Publ. Inc., New York, NY. 251 pp.
5. GREGORY, P. H. 1968. Interpreting plant disease dispersal gradients. Annu. Rev. Phytopathol. 6:189-212.
6. HIRST, J. M., and G. W. HURST. 1967. Long-distance spore transport. Pages 307–344 in: P. H. Gregory and J. L. Monteith, eds. Airborne Microbes. Soc. Gen. Microbiol. Symp. 17. 385 pp.
7. KRAMER, C. L., and S. M. PADY. 1966. A new 24-hour spore sampler. Phytopathology 56:517-520.
8. LONG, D. L., and C. L. KRAMER. 1972. The air spora of two contrasting ecological sites in Kansas. J. Allergy 49:255-266.
9. PETERSON, R. F., A. B. CAMPBELL, and A. E. HANNAH. 1948. A diagrammatic scale for estimating rust intensity of leaves and stems of cereals. Can. J. Res. Sect. C. 26:496-500.
10. ROELFS, A. P. 1972. Gradients in horizontal dispersal of cereal rust urediospores. Phytopathology 62:70-76.
11. SLADE, D. H. 1968. Meteorology and atomic energy. U.S. Atomic Energy Commission. Division of Technical Information TID 24190. 445 pp.