Meteorological Conditions Associated With Long-Distance Dissemination and Deposition of Puccinia graminis tritici Uredospores in India

S. Nagarajan, Hardev Singh, L. M. Joshi, and E. E. Saari

Division of Mycology and Plant Pathology, Indian Agricultural Research Institute (IARI), New Delhi-110012; Department of Botany, University of Delhi, New Delhi-110007; Division of Mycology and Plant Pathology, IARI; and The Ford Foundation, Beirut, Lebanon, respectively.

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ABSTRACT

Long-distance spread of the airborne wheat stem rust uredospores depends on upper-air weather patterns. Trajectories of the airborne inoculum at the 700 millibar (mb) level led from the Nilgiris, the source area, to the secondary foci of infection. Drawings of the 700-mb trajectories were identical to the cloud system movement shown in the weather satellite imagery. Satellite imagery may be used to study uredospore transport and deposition. A schematic model is proposed for the spread and recurrence of stem rust of wheat in India.

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Additional key words: trajectories, Satellite Television Cloud Photograph (STCP), tropical cyclone.

In India, wheat often is damaged by stem rust [caused by *Puccinia graminis* Pers. f. sp. *tritici* (Eriks. & Henn.)]. Mehta (6) showed that collateral and alternate hosts were epidemiologically insignificant in India. He concluded that uredospores spread from the Nilgiris and Palni hills in south India, and from central Nepal in the Himalayas (7). Recent investigations show that stem rust uredospores spread from the Nilgiris, which extends up to 2,637 meters (4,8). In these hills, wheat is grown throughout the year which facilitates repeated cycles of the uredial stage.

Rain-sampling experiments conducted in the USA (15) and in India (8) using the rain sampler of Roelfs et al. (14), trapped uredospores weeks ahead (8) of the disease appearance on a susceptible cultivar. Based on this study in India, Nagarajan and Singh (10) formulated certain synoptic upper air rules called the "Indian stem rust rules." Combinations of weather conditions which satisfy these rules result in transportation and deposition of inoculum from the Nilgiris hills area. They found that the path of airborne inoculum could be correlated with the visible cloud movements detected by Satellite Television

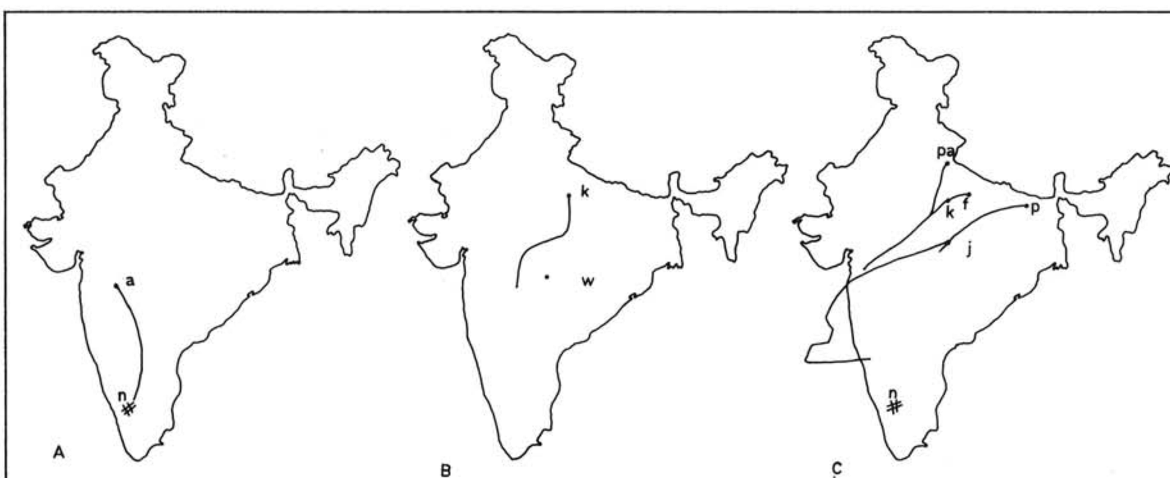

Fig. 1-(A to C). Transport of *Puccinia graminis tritici* uredospores in India. **A)** The 700-mb level air trajectory for the probable airborne inoculum of Ahmednagar (a) originated over the Nilgiris hills (n) and traversed 900 km in 36 hours. **B)** In 48 hours the 850-mb trajectory of Kanpur had moved 700 km north from over the infected fields of Wardha (w). **C)** The 700- and 850-mb combination trajectory for Jabbalpore (j) after 150 hours led southwards. The 700-mb trajectory for Pusa (p) ended over Jabbalpore, and the Pantnagar (pa), Faizabad (f) and Kanpur (k) trajectory for 700 mb shows that they are off-shoots of the Jabbalpore trajectory.

Cloud Photographs (STCP's) of the weather satellite Environmental Sciences Services Agency, ESSA-9 (9).

MATERIALS AND METHODS.—Rain samples mailed by cooperators were analysed for total uredospore content by the methods of Rowell and Romig (15). Because the samples were free of organic matter, a minor modification was made in the counting procedure (8). The uredospore counts mentioned in the text refer to total

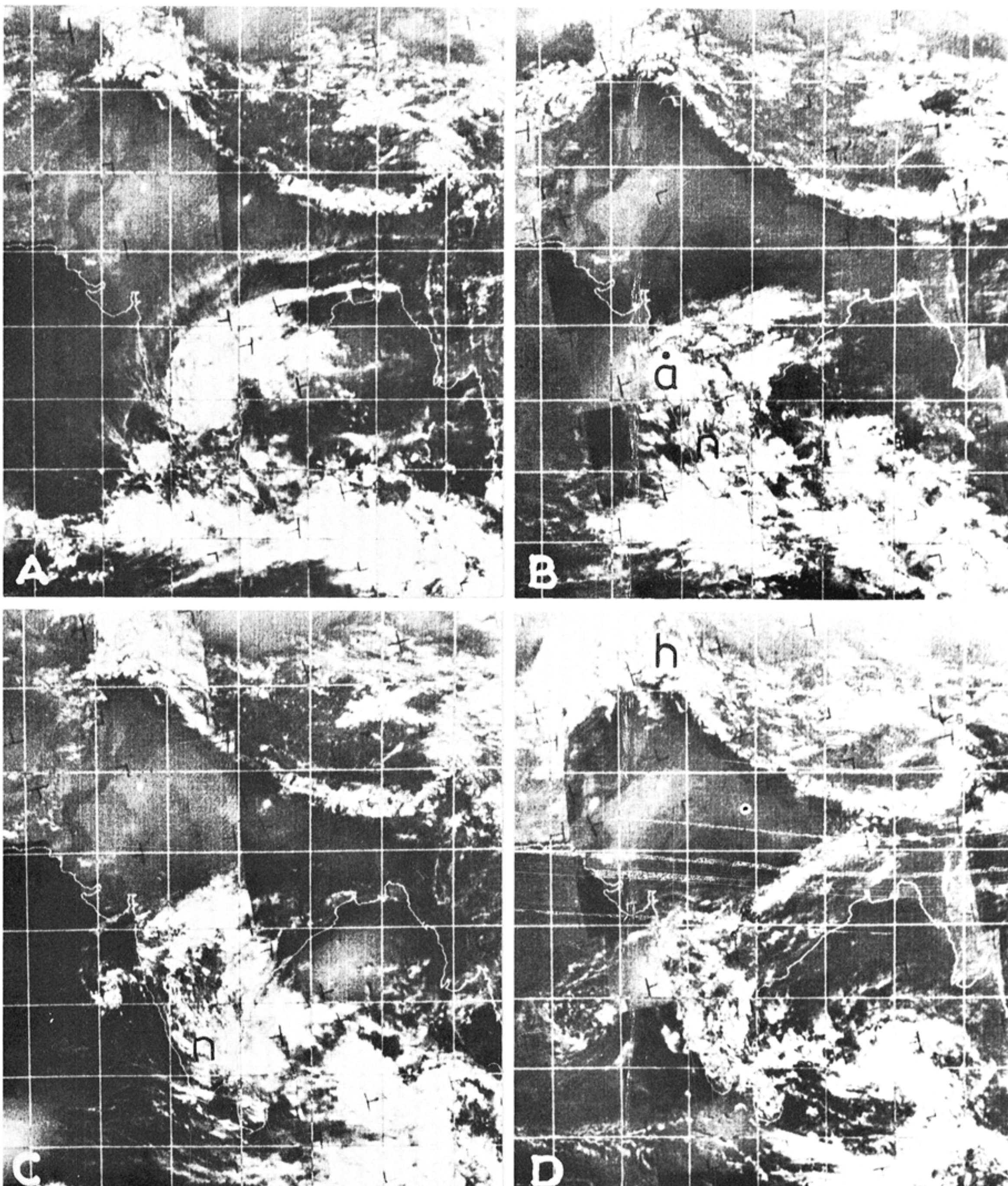

Fig. 2-(A to D). Transport of *Puccinia graminis tritici* uredospores in India. Photograph of a tropical cyclone that was an efficient uredospore carrier. **A)** The Satellite Television Cloud Photographs (STCP) of ESSA-9 on 4 November 1968 shows a huge organized, spiral cloud mass over the Coramandal Coast. **B)** On the subsequent day it crossed the coast and decayed. **C,D)** Leaving a huge mass of clouds over central India.

number per sample. When uredospores were observed in the rain samples, synoptic weather charts for 700- and 850-mb levels (approximately 3,000 m and 1,600 m, respectively) were obtained from the India Meteorological Department. Following Petterssen's method (11) backward air trajectories were drawn for the airborne inoculum. Corresponding successive cloud images taken by the weather satellite ESSA-9 were studied with the trajectories. Ground-level observations of the dates, time, and severity of infection by the rust fungi were also made on a susceptible wheat cultivar.

RESULTS.—*Ahmednagar, 7 November 1968*.—During January 1969, stem rust was reported on local cultivars from many parts of Mysore and Ahmednagar area of Maharashtra. Artificially induced field epiphytotics of stem rust showed that 55-60 days are required to reach 50-60% severity when the primary inoculum level is at one pustule/238 culms (8). Under such conditions, deposition of the primary inoculum must have occurred along with the meteorological conditions that prevailed during November 1968. Thus, the rain charts were checked and precipitation was noted on 7 November. Trajectories were drawn for the path of probable inoculum movement to Ahmednagar. The path ended very close to the Nilgiris hills (Fig. 1-A). These uredospore transport trajectories covered a distance of 960 km in about 36 hours.

The 700-mb charts showed a storm crossing the coast on 5 November. After it crossed the coast, the storm became a weak cyclonic circulation of air. On 7 November, the low pressure moved to the south Kongan coast, which maintained a southerly wind over the Ahmednagar area. During these days, temperature at this level was much above freezing. The STCP of 4 November, showed a shield of spiral clouds of the tropical storm. On crossing the land, the storm weakened and moved westwards. On 6 November, the system decayed quickly, and clouds were seen covering peninsular India in patches. The then-visible northerly movement of the cloud system showed that southerly winds were prevailing (Fig. 2 A-D).

Kanpur, 14 January 1970.—14 January 1970 rainfall at Kanpur deposited 10 uredospores. The 850-mb trajectory passed southward, made an arc, and ended close to Wardha in central India (Fig. 1-A). The uredospores travelled a distance of 700 km in 48 hours and were washed down by rain over Kanpur. The 850-mb weather charts for this period showed an anticyclone over central India. As a result, air from central India was pushed out. A trough that extended north of the anticyclone on the subsequent days further pushed the system towards Kanpur. Satellite images of 12 January, were free of clouds over north India. On 13 January, unorganized masses of clouds were recorded over 73-78° E; 15-° N, moving from the south-west, passing over the infected fields of Wardha. They were recorded after 25 hours over Kanpur where they resulted in precipitation (Fig. 3 A-C).

Spore shower over north India.—Rain samples of 19 January 1971 from Jabbalpore had 50 and 2,290 uredospores of stem rust. Powerkeda (200 km west of Jabbalpore) had 10 uredospores in the rain sample. Trajectory for 700- and 850-mb after 150 hours were traced to the Nilgiris hills (Fig. 1-B). Trajectories for the first 30 hours of probable spore movement were traced at 700-mb, and the rest at 850-mb. The change in height that occurred near the Kongan coast (75° E; 22° N) reflected a sudden ascent of the anticyclonic air mass that was moving from the south. Moisture in this rising warm air condensed to form the altostratus clouds that were noted in the STCP of 18 January (Fig. 4-A).

The 850-mb charts between 12-17 January 1971, showed an anticyclone over central India. This created southerlies of 0.26-0.51 m/second (5-10 knots/hour) over central and the temperature ranged between 5-18 C. On 18 January, at 700-mb the upper air temperature ranged between 4 and −2 C, with a well-defined temperature

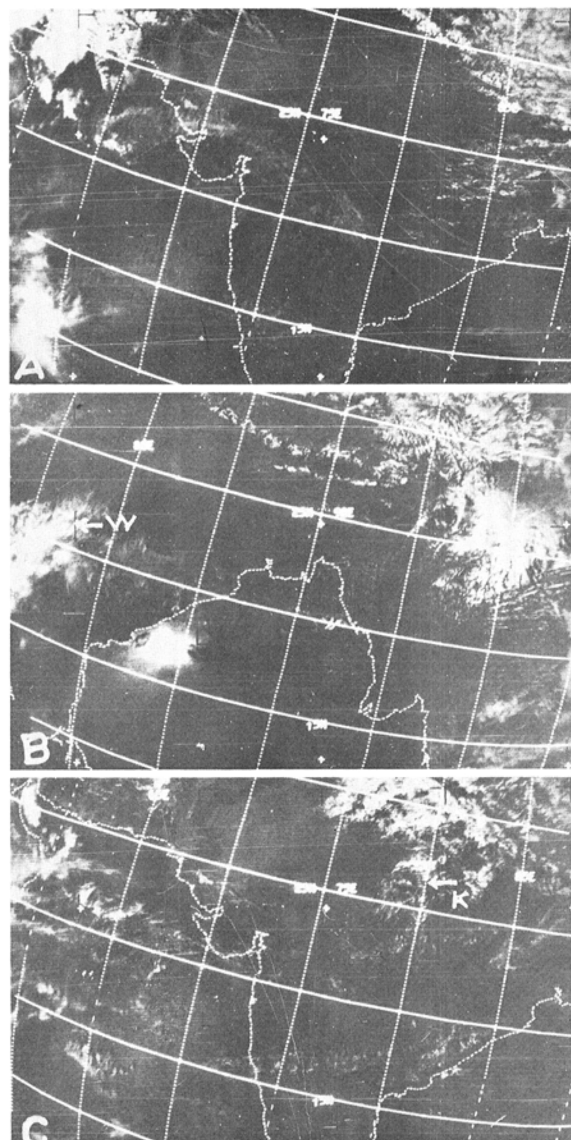

Fig. 3-(A to C). Transport of *Puccinia graminis tritici* uredospores in India. **A**) On 21 January 1970 clouds are completely absent over north India. **B**) Altocumulus type of clouds are seen over the diseased area of Wardha (w), 70-80° E; 15-23° N. **C**) On 14 January clouds system has moved to Kanpur (k) 75-80° E; 25-30° N.

profile. On that day, the 850-mb charts showed a frontal system exactly over Jabbalpore. On 18 January, the STCP for the subcontinent recorded a thin layer of unorganized and not clearly distinguishable altostratus cloud over 75° E; 25° N. This system moved eastward, and was photographed the next day with an abrupt honeycomblike end extending toward the southwestern side, and lying exactly over the Jabbalpore-Umaria region of Madhya Pradesh (Fig. 4-A,B).

Spore shower over Pusa.—On 20 January 1971 280 uredospores were found in the rain sample from Pusa. A study of the 700-mb chart for that day showed the wind flow to be northeasterly. The 700-mb trajectory moved southwest and reached Jabbalpore when the spore cloud

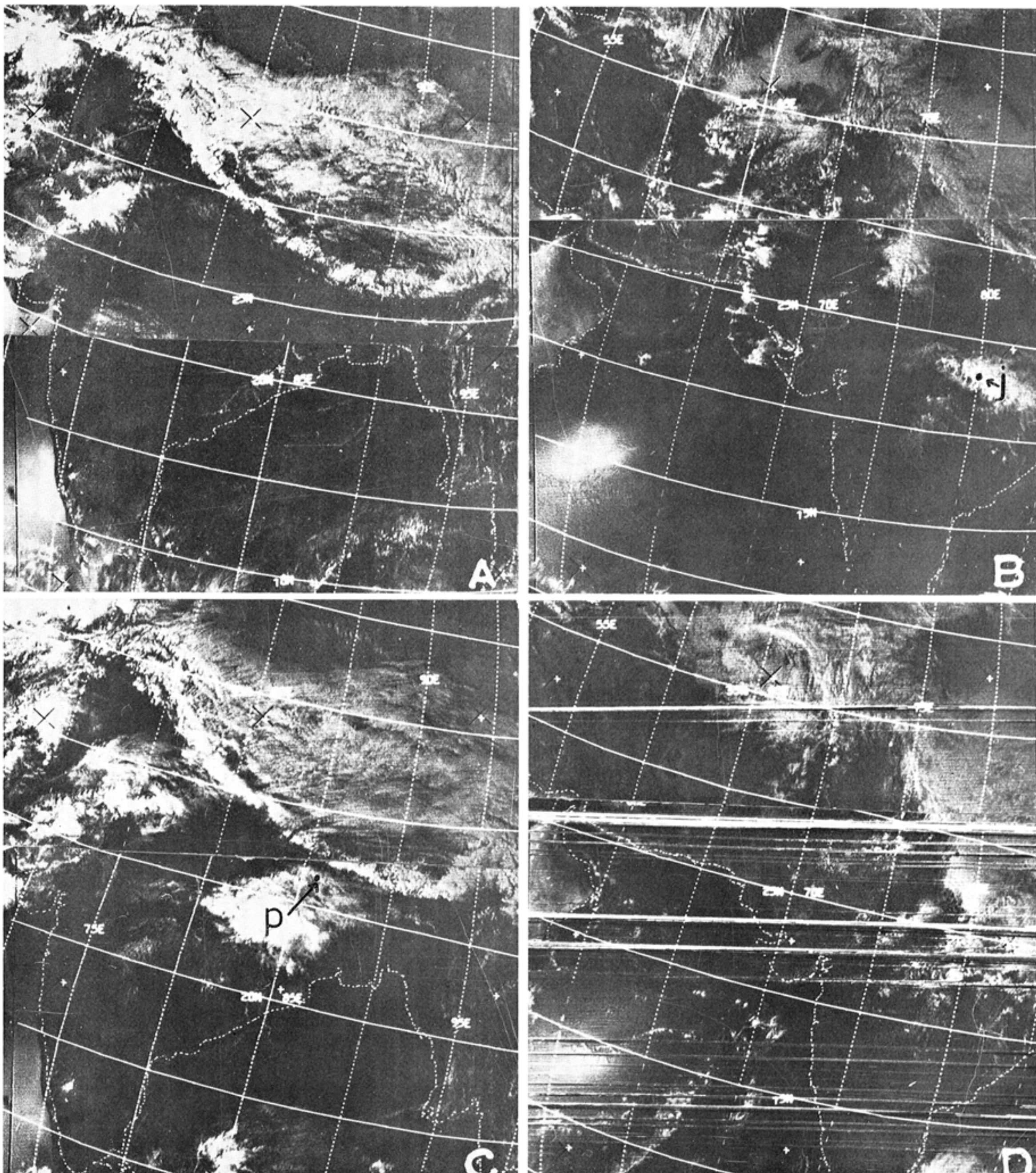

Fig. 4-(A to D). Transport of *Puccinia graminis tritici* uredospores in India. **A**) On 18 January 1971 light patches of clouds are seen near 75° E; 20-23° N. Snow-covered Himalayas and Tibetian plateau are seen as white reflections. **B**) Honeycomblike structures due to a 'front' seen over Jabbalpore (j) the next day. **C**) Altocumulus clouds seen over 80-88° E; 22-24° N over Pusa (p) on 20 January 1971. **D**) The cloud system had merged with that of western disturbance resulting in cloud coverage over the whole of north India.

was over there (Fig. 1-C). On 20 January, the cloud system that had been over Jabbalpore had moved northeast and reached eastern Madhya Pradesh, eastern Uttar Pradesh, and Bihar (Fig. 4-C).

Kanpur, Faizabad, and Pantnagar spore washdowns.—Rain samples from Kanpur, Faizabad, and Pantnagar had 90, 10, and 280 uredospores, respectively. The 700-mb level trajectory for Pantnagar moved southward and joined with that of Faizabad and Kanpur (Fig. 1-D). Presence of western disturbance over Jammu and Kashmir resulted in northwesterly winds of 0.76-1.02m/second (15-20 knots/hour). This transported part of the inoculum from Jabbalpore to all these places. The STCP of 21 January 1971 showed that the cloud system under discussion merged with the western disturbance covering parts of Uttar Pradesh and Bihar (Fig. 4-D).

DISCUSSION.—The winter rains of 1971 resulted in a spore shower over Powerkeda, Jabbalpore, Pusa, Kanpur, Faizabad, and Pantnagar. Trajectories drawn for the spore showers of these places joined with each other which ultimately originated close to the Nilgiris hills (Fig. 1-B,C). Thus, uredospores produced in the Nilgiris area probably were transported by wind and were deposited by rain over central India and the Indo-Gangetic plains. Mehta (7) concluded that from December - January onwards stem rust spreads from central Nepal to the wheat-growing Indo-Gangetic plain and little earlier than this, from the Nilgiris to south and central India. The spore shower of Kanpur and Ahmednagar, and the later spore cloud over the north, suggest the inoculum source to be the Nilgiris hills. This also confirms the finding of the recent workers (4,8).

Present studies show the probable height of spore travel to be around 700-mb (8). Because the Nilgiris hills are ~2,637 meters high, uredospores from these hills are lifted by convection currents to 700-mb level and transported hundreds of kilometers. Spores which reach the 1,500-m level theoretically could be carried 1,760 to 1,920 km by a wind speed of 48 km/hour before being deposited (16). In nature, vertical mixing and small eddies occur (2) which help to maintain the height of the spore cloud during transport.

Paths of the 700- and 850-mb trajectories of the windborne uredospores and the path of the cloud system shown by STCP's were identical. Therefore, STCP's could be used to study long-distance transport of spore clouds and their deposition by rain. Clouds less than 1,800 m thick do not produce rain and the probability of rain increases with clouds over 3,600 m deep (12). Clouds less than 270 m high generally do not occur in India (5). Hence, it is logical that the 700-mb trajectory follows the path of the rain-producing cloud systems that are photographed by the weather satellite.

Disease incidence during 1968-69 was related to the November rain that occurred as a result of the tropical cyclone. As a result of the cyclone, strong winds and a thick cloud mass passed over the Nilgiris. Nagarajan and Singh (9) correlated the occurrence of the Wardha wheat stem rust epidemic to similar weather conditions. Under such conditions, inoculum can be transported more than 960 km in one stretch, sometimes without detectable deposition in between. When the ground surface is heated by insolation, the lowest layer of air gets heated, and if a large temperature lapse rate is established, the atmosphere becomes unstable and the lighter ground-level air raises. Such rising convection currents carry a load of microorganisms upward (3), and even uredospores from heavily rust-infected wheat fields can move upward this way (13).

Based on these studies, an epidemiological model on the spread of wheat stem rust is proposed. Stem rust inoculum is always present in the Nilgiris hills that are 2,637 m in elevation. A majority of the tropical cyclones formed during November in the Bay of Bengal or the Arabian Sea close to the Nilgiris, after crossing the coast curve and dissipate over central India (1). This system creates fast-moving winds which enable efficient spore take-off from the Nilgiris hills. Along with the cyclone, uredospores are transported for hundreds of kilometers and deposited by rain. Disease appearance is noted first exactly below the place, where the tropical cyclone dissipates. Spore showers during November followed by warm, moist conditions during January and February, resulted in severe wheat rust epidemics. From such foci in central India, the pathogen spreads to Bihar and eastern Uttar Pradesh during January or February. Such a spread is enabled by the precipitation and westerlies created by western disturbances. If ground-level weather conditions are favorable, moderately severe epidemics can result. In the absence of tropical cyclones, anticyclonic weather over central India could transport uredospores to central India during January or February. However, that transportation of inoculum occurs too late in the crop season to result in an epidemic.

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