The Effect of Climate Variability on Stripe Rust of Wheat in the Pacific Northwest

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Research supported by the Advanced Study Program, National Center for Atmospheric Research (NCAR), Boulder, CO 80307, and a National Science Foundation Grant ATM 76-21725, Climate Dynamics Program.

Acknowledgement is made to NCAR, which is sponsored by the National Science Foundation, for all computer time used in this research.

The author expresses appreciation to Robert G. Emge, Roland F. Line, and Robert L. Powelson for information on stripe rust occurrence in the Pacific Northwest.

Accepted for publication 20 June 1977.

ABSTRACT

COAKLEY, S. M. 1978. The effect of climate variability on stripe rust of wheat in the Pacific Northwest. Phytopathology 68: 207-212.

Wheat stripe rust (*Puccinia striiformis* West) epiphytotics are confined predominantly in the USA to the Pacific Northwest and intermountain states because of the climate. Because stripe rust epiphytotics have been frequent only since 1960, the possibility that climate variability could explain in part the pattern of epiphytotics was investigated. Detailed meteorological data for 1961-1975 were obtained for Pendleton, Oregon; temperature, precipitation, relative humidity, and combinations of these variables were studied for various time segments of data. An increased number of days in January and February with favorable temperatures for rust development could be used to separate years of severe epiphytotics from mild stripe rust years. In 1961-1975, the average temperature in January and February was 2 C higher than for those same months in 1935-1960. In contrast, the average April temperature was over 1.2 C cooler. Warmer-than-normal winter and cooler April temperatures favor the development of stripe rust epiphytotics. Cool spring temperatures delay temperature-sensitive adult-plant resistance in wheat cultivars such as Gaines and Nugaines.

Additional key words: epidemiology, nonspecific resistance.

Stripe rust of wheat, caused by *Puccinia striiformis* West. (*P. glumarum* Eriks. and Henn.), apparently is restricted in its occurrence in the USA primarily to the Pacific Northwest and intermountain states because of climate. A historical perspective of stripe rust provides information on what climatic factors limit its distribution.

Stripe rust was first recognized in the USA in 1915 (4). However, it is probable that the fungus had been present since 1892, but was confused with other rust fungi (8). The early workers noted that the disease occurred only in the Western states but they were concerned that the pathogen would spread eastward to the major wheat growing areas of the Great Plains (9, 10, 12). Stakman (24) wrote in 1930 that it was not known whether resistant varieties or unfavorable meteorological conditions were responsible for the absence of stripe rust in the Central Plains. Newton and Johnson (18) speculated that the limitation of stripe rust to Western Canada was the result of high summer temperatures which prevented the spread of the stripe rust fungus to the prairie provinces and also rendered susceptible hosts resistant. Humphrey et al. (11) summarized in 1935 that stripe rust epiphytotics were most likely when late summer and fall infections occurred, when abundant mycelium survived the winter, and when cool nights, warm days, heavy dews, and abundant sunshine occurred during the spring and summer growing season.

Reports on the occurrence of stripe rust were fairly frequent from 1916-1938. Following the late 1930's, stripe rust attracted little attention until 1957 when the first epiphytotic of stripe rust in the Great Plains occurred in Texas (6). That same year, stripe rust was reported for the first time in Kansas and Oklahoma (20, 28). In 1958, a second stripe rust epiphytotic was reported for Texas (7) and for Kansas, where losses were estimated at about 1% (19). Also in 1958, stripe rust was reported for the first time in Minnesota (17). By that time, it was known that the stripe rust fungus is favored by cool temperatures and, unlike other cereal rusts, can even function at relatively low temperatures; weather records in the Great Plains states were scrutinized for unusual conditions and spring temperatures were found to be cooler than normal with abundant rainfall (6, 20, 28). The development of stripe rust under warm conditions in Texas in 1958 led researchers to speculate that a new fungus race might have evolved. (7). In 1959-1960 and 1960-1961, damaging stripe rust outbreaks occurred in Washington. In 1961, stripe rust cost wheat growers in Oregon approximately \$15 million (22), and a severe stripe rust attack occurred for the first time in California (25). These and subsequent outbreaks have prompted numerous research articles on the epiphytology of stripe rust.

The meteorological factors which favor stripe rust infection and development can be briefly summarized as follows: Three or more hours of free moisture as dew or rain is required for the germination of urediospores and

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the infection of the wheat plant (3, 5, 22). The various temperatures reported for infection include 6 to 22 C (22), 0.5 to 15.5 C (5), and 2 to 13 C with 7 C optimum (23). Infection in the field can occur from −4 to 17 C (3). Constant or mean temperatures above 22 to 25 C inhibit and may even eliminate the stripe rust fungus (22, 23, 25).

Wheat cultivars differ in their susceptibility to *P. striiformis* (2, 13). Sharp found that the host reaction type to the stripe rust fungus was influenced greatly by the environment (23). Lewellan et al. (14) evaluated the effect of temperature changes on the major and minor genes in wheat for resistance to *P. striiformis*. They found that only minor genes were affected by different temperature profiles and that these gave better resistance at a higher temperature profile (15/24 C) than at a lower profile (2/18 C).

The usefulness of a particular major gene (or race-specific) resistance to stripe rust has been short-lived in the Pacific Northwest because new rust races have evolved to attack resistant hosts (1, 15, 16, 21). Line et al. (16) evaluated the resistance-types to stripe rust found in wheat cultivars. Resistant-type (R-type) 7 was the most important in the Pacific Northwest. Cultivars with R-type 7 were very susceptible in the seedling stage at all temperatures tested and in later growth stages at low temperatures. Resistance increases at the higher temperatures which normally accompany host development. No race specificity to R-type 7 has been detected in more than 12 yr. Line also summarized the history and resistance types of the wheat cultivars grown in the Pacific Northwest. With the exception of the white club wheats (Elgin, Elmar, Omar, Moro, and Paha which are now susceptible to some or all existing stripe rust races), most cultivars grown since the 1940's have good nonspecific resistance. Gaines and Nugaines are the most popular cultivars grown east of the Cascades; both have temperature sensitive adult-plant resistance and are dependent on warm temperatures to trigger their R-type 7 resistance (16).

Since 1960, stripe rust outbreaks have been frequent. Some changes in cultural practices have occurred, such as the increased use of irrigation east of the Cascade Mountains. I do not believe the changes in cultural practices and the history of the cultivars grown in the Pacific Northwest can explain adequately why stripe rust was of apparently minor importance between its appearance in the early 1900's and the first epiphytotic in 1961. This research was undertaken to determine if a change in climatic conditions (climatic variability) was partly responsible for the increased frequency and severity of stripe rust ephiphytotics since 1960.

TABLE 1. Monthly apparent infection rates (r) for stripe rust of wheat (caused by *Puccinia striiformis*) epiphytotics in the Columbia Basin counties[a] of eastern Oregon, for the years 1969-1975

	Apparent Infection Rate (r)[b] for the month of:				
Year	Feb	Mar	Apr	May	Jun
1969	.083	.079	.077	.097	.137
1970	.103	.030	.067	.147	.127
1971	.005	.005	.006	.216	.241
1972	.006	.006	.060	.168	.233
1973	.007	.008	.140	.161	.157
1974	.057	.067	.072	.110	.167
1975	.093	.065	.079	.072	.308

[a]Wasco, Sherman, Gilliam, Morrow, and Umatilla Counties.
[b]Based on random field observations of natural infections and calculated using an estimate of disease severity at the beginning and end of each month, by van der Plank's equation:

$$r = \frac{1}{t_2 - t_1}\left(\text{Log}_e \frac{X_2}{1-X_2} - \text{Log}_e \frac{X_1}{1-X_1}\right)$$

where t_2-t_1 = days in month and X_1 and X_2, the amount of disease (%/100) at the beginning and end of the month. Compiled by R. L. Powelson, Dept. Botany and Plant Pathology, Oregon State University, Corvallis).

MATERIALS AND METHODS

The main wheat-growing area of eastern Oregon is the Columbia Plateau which is bounded on the west by the Cascade Mountains, to the south by the high country of central Oregon, on the east by the Blue Mountains and to the north by the Columbia Basin. Wheat is grown also in the Willamette Valley of Oregon which is situated between the Cascade Mountains and the Coast Range.

Local Climatological Data for the 1960-1975 were obtained for Pendleton, Oregon which is located on the Columbia Plateau. The Meteorological data were collected by the Weather Service Office at the Pendleton Airport, about 1.8 km northwest of downtown, at an elevation of 454.8 m. These data were comprised of observations made at 3-hr intervals of: sky cover, ceiling visibility; air, wet bulb, and dew-point temperatures; relative humidity; direction and speed of wind; and weather type (e.g., fog, rain, snow). Hourly precipitation was recorded. The above data were summarized on a daily and monthly basis; reports were issued monthly (27). Annual summaries which include monthly temperature averages and precipitation data beginning in 1900 were also obtained (26).

Disease severity data were obtained from researchers who have worked with stripe rust in the field. R. G. Emge (Plant Pathologist of the U.S. Department of Agriculture, Plant Disease Research Laboratory at Frederick, MD 21701) provided descriptive and quantitative information on disease development for 1969-1975. R. L. Powelson (Dept. Plant Pathology and Botany, Oregon State University, Corvallis, OR 97331) provided descriptive data in the form of monthly narratives from 1959-1967, and quantitative data for 1968-1975. Additional information on stripe rust epiphytotics was obtained from Shaner and Powelson (22).

RESULTS

Stripe rust has been present to some extent on susceptible wheat cultivars every year since 1961. Based on the descriptive data available for 1959-1967 [Powelson, *personal communication* and (22)], the most severe stripe rust epiphytotics on the Columbia Plateau and adjacent Columbia Basin in Oregon occurred in 1961 and 1967. For 1969-1975 (Table 1), stripe rust was the most severe in 1975.

Daily and hourly weather data from Pendleton, Oregon, were analyzed to determine if there were any differences between the climatic conditions of years rated as severe or mild stripe rust. No differences in the frequency, quantity, or type of precipitation could be used to separate years of severe rust from years of mild stripe rust. Based on research done by Emge and Johnson (5) and Shaner and Powelson (22), favorable temperatures for the development of stripe rust epiphytotics were defined as 5.6-22.2 C. Meteorological data were summarized as:

$$\frac{(\text{No. days } 5.6 \leqslant X \leqslant 22.2\text{C}) - (\text{No. days } X \leqslant 1.12\text{C when no } X \geqslant 5.6\text{C})}{\text{No. possible days}}$$

Where X = temperature measured for any 3-hr interval. Years of severe rust all had an above-average ratio of days favorable for stripe rust in January and February.

Monthly and yearly temperature, precipitation, and snowfall averages for 1935-1974 were studied to determine if climatic conditions during 1935-1960 were different from those for 1961-1974. For 1961-1974, the average monthly January temperature was 1.84 C, in February was 2 C, and in June was 1.2 C higher than for those same months in 1935-1960. In contrast, the average April temperature was 1.2 C lower in 1961-1974 than during 1935-1960. Other months showed smaller differences between time periods (Fig. 1). The annual average temperature was 0.5 C higher during the 1961-1974 period.

When the average monthly precipitation totals for 1935-1960 were compared with those for 1961-1974, the averages differed less than 13.5 mm in any month (Fig. 2).

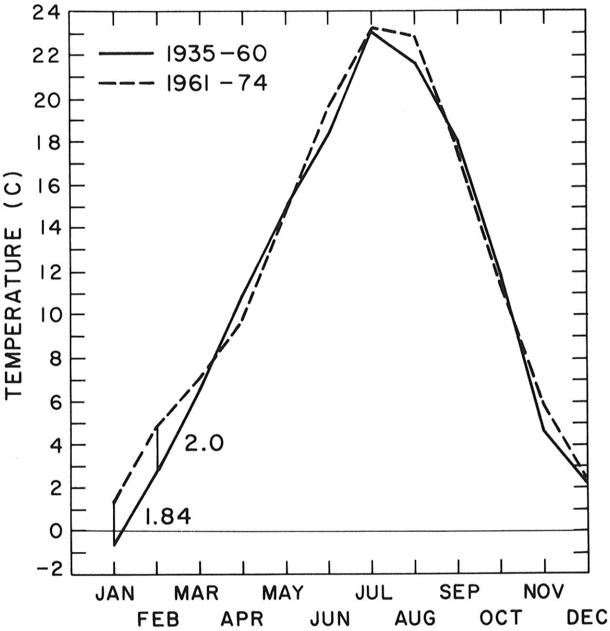

Fig. 1. Average temperature for Pendleton, Oregon. Data source: National Oceanographic and Atmospheric Administration — Environmental Data Service (NOAA-EDS) — National Climatic Center, Local Climatological Data, Annual Summary, 1974.

October-to-April snowfall totals were averaged for 1935-1960 and for 1961-1974 (Fig. 3). December snowfall for 1961-1974 averaged 49 mm greater than for

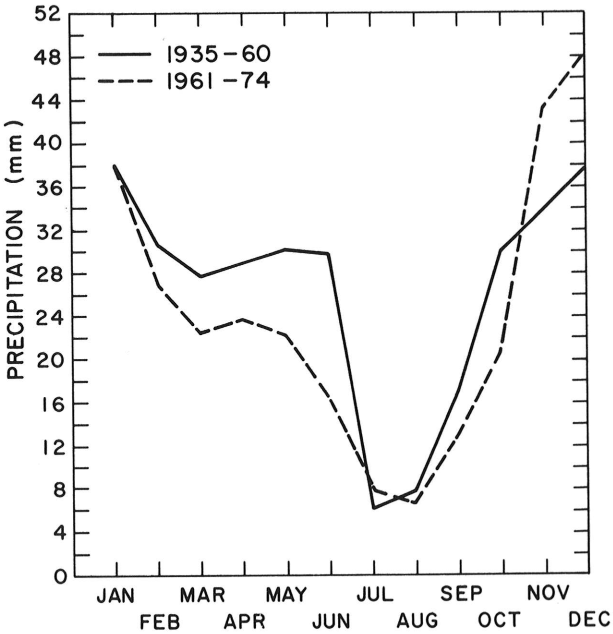

Fig. 2. Average precipitation for Pendleton, Oregon. Data source: National Oceanographic and Atmospheric Administration — Environmental Data Service (NOAA-EDS) — National Climatic Center: Local Climatological Data, Annual Summary, 1974.

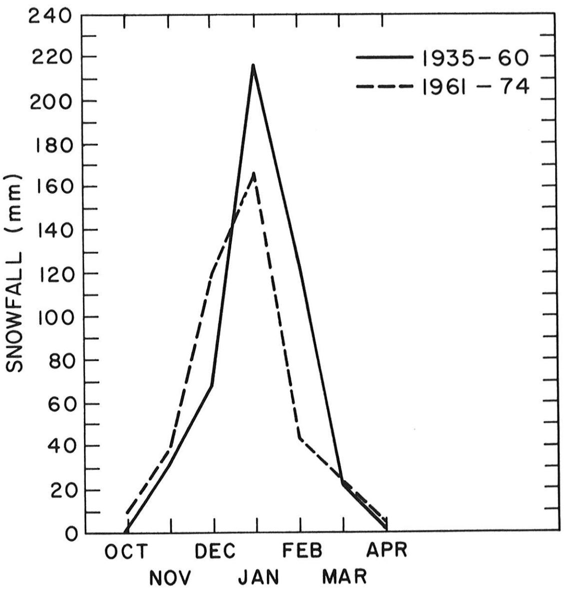

Fig. 3. Average monthly snowfall for Pendleton, Oregon. Data source: National Oceanographic and Atmospheric Administration — Environmental Data Service (NOAA-EDS) — National Climatic Center: Local Climatological Data, Annual Summary, 1974.

1935-1960 and corresponded with an average December temperature decrease of 0.3 C from 1935-1960 to 1961-1974. In contrast, average January and February snowfall decreased 49 and 84 mm, respectively, from 1935-1960 to 1961-1974. This decrease is consistent with the recorded increases in average January and February temperatures. The correlation coefficients between average temperatures and snowfall totals is negative (Fig. 4). The correlation coefficients are significant at P = 0.05 for November and December, at $P = 0.01$ for January and February, and at $P = 0.001$ for March.

Five-year moving averages for monthly temperature data were calucalated for 1905-1975. Average February temperatures show a predominant warming trend since the late 1930's. Five-year averages since 1960 have been above the mean moving average for 1905-1974 (Fig. 5). Average April temperatures show a cooling trend since the 1930's with average temperatures since 1960 below the mean moving average for 1905-1974 (Fig. 6).

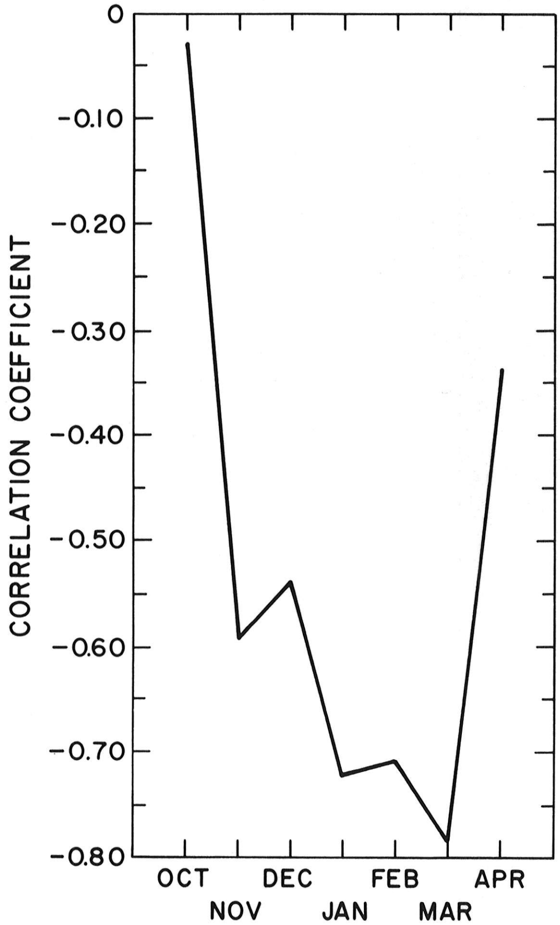

Fig. 4. Correlation between monthly average temperature and snowfall for 1935-1974 for Pendleton, Oregon. Data source: National Oceanographic and Atmospheric Administration — Environmental Data Service (NOAA-EDS) — National Climatic Center: Local Climatological Data, Annual Summary, 1974.

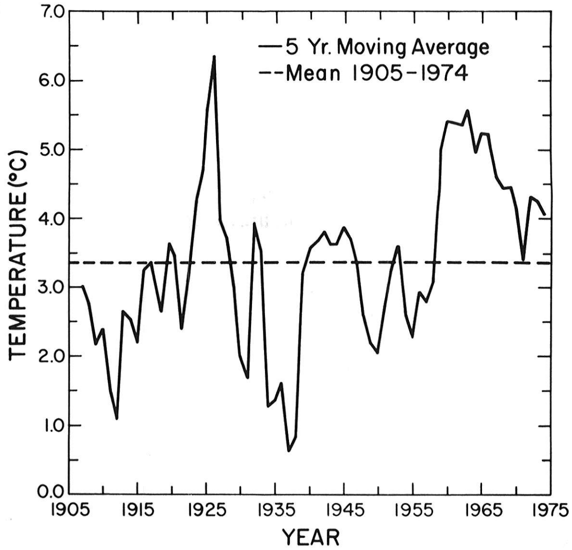

Fig. 5. Five-year moving average for February average temperature at Pendleton, Oregon. Based on data from: National Oceanographic and Atmospheric Administration — Environmental Data Service (NOAA-EDS) — National Climatic Center, Annual Summary, 1949 and 1975.

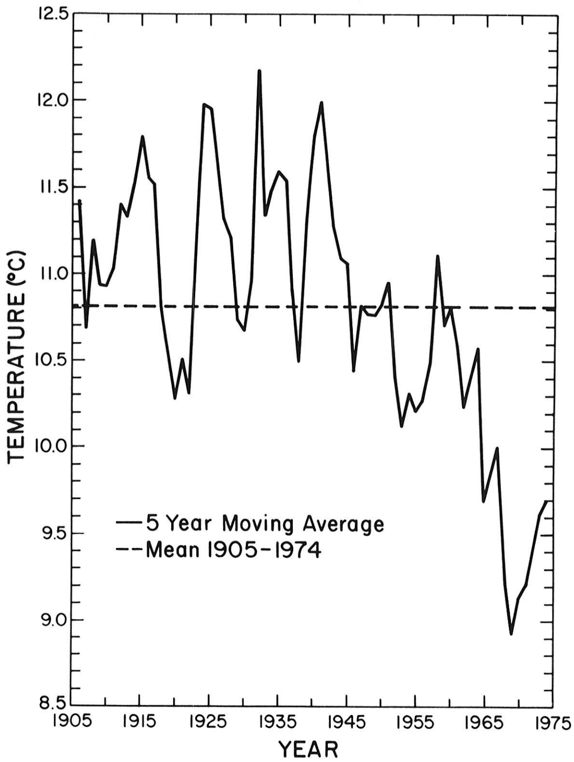

Fig. 6. Five-year moving average for April average temperature at Pendleton, Oregon. Based on data from: National Oceanographic and Atmospheric Administration — Environmental Data Service (NOAA-EDS) — National Climatic Center, Annual Summary, 1949 and 1975.

DISCUSSION

The results of this research indicate that the climatic variation in the Pacific Northwest has been of sufficient magnitude to affect the frequency and severity of stripe rust epiphytotics. Consider the changes in winter temperatures and snowfall.

All severe epiphytotic years (1961, 1967, and 1975) had warmer-than-normal temperatures in January (average, 2.4 C above normal). Normal is defined here as the average monthly temperature for the 1961-1975 period. The average December temperature in 1960 was below normal, but a snowcover protected the wheat foliage and hence the fungus from winterkill. The epiphytotics in 1967 and 1975 were preceded by temperatures in December which were respectively 2.6 and 2.3 C above normal (Table 2). February temperatures in 1961 and 1967 averaged 2.7 and 1.67 C respectively above normal. Widespread but less severe stripe rust developed in 1971, 1972, and 1974; all of these years had at least one winter month with above normal temperatures. Two other years, 1964 and 1966, had the potential in early spring for serious stripe rust epiphytotics in eastern Oregon because of the unusually mild winters.

The effect on stripe rust of the recorded climatic variation in the winter season can be summarized. The overall trend of increased December snowfall since 1960 would provide better protection of the wheat and the fungus from winterkill. Decreased snowfall in January and February reflects only the increased average temperatures and would not adversely affect the fungus. Warmer temperatures in January and February have two direct effects on stripe rust. The first is the survival of fall-infected wheat foliage, the second is the shortening of the latent period of the fungus. The latent period (time between penetration and sporulation) for *P. striiformis* in wheat decreases with increasing temperature. The shorter the latent period, the more rapidly the fungus can spread to healthy plants. The average February temperature for the most severe epiphytotic years of 1961, 1967, and 1975 was 5.74 C which corresponds to a latent period of 29 days. This is much shorter than the average latent period calculated for February in 1935-1960 and 1961-1975. In contrast, the cooler-than-normal April temperatures for 1961-1975 lengthen the latent period only slightly (Table 3).

The trend of cooler April temperatures is particularly important in stripe rust epiphytology because of the effect of temperature on host plant resistance. The predominant wheat cultivars grown since the epiphytotic in 1961 have been Gaines and Nugaines, which are both dependent on warm spring temperatures to trigger adult-plant resistance. Cooler-than-normal April temperatures accompanied the severe epiphytotics in 1967 and 1975, and the milder epiphytotics in 1971 and 1972. In 1967, 1975, and 1971, the cooler temperatures were accompanied by above-normal precipitation which would provide very favorable conditions for fungus infection. Although April temperatures in 1961 and 1974 were above normal, both months had above-normal rainfall and both years were followed by below-normal temperatures in May. In 1966, a potentially severe epiphytotic failed to develop when above-average temperatures in April and May were accompanied by below-normal rainfall.

Fortunately, the cooling trend in April temperatures has been accompanied by a warming trend in June which has probably helped to limit economic losses due to stripe rust on cultivars with nonspecific, temperature-sensitive resistance. The changes in spring temperature patterns since 1960 that have favored stripe rust have probably been compensated for somewhat by the decreased precipitation averages for March-June. Although precipitation cannot be used alone to explain patterns of stripe rust epiphytotics, it is particularly important in years such as 1964 when a dry warm winter was followed by below-normal precipitation and below-normal temperatures

TABLE 2. Average monthly temperatures at Pendleton, Oregon

Year	Month[a]						
	Jan (C)	Feb (C)	Mar (C)	Apr (C)	May (C)	Jun (C)	Dec (C)
1961	2.8	7.5	7.9	10.1	14.1	22.0	2.7
1962	0.2	4.3	6.4	12.1	12.2	18.4	4.1
1963	−2.8	6.0	7.4	8.9	14.9	18.8	0.4
1964	4.6	5.1	6.4	9.2	13.8	18.3	0.5
1965	1.9	5.1	4.8	11.6	14.4	18.9	2.7
1966	3.5	4.3	7.4	11.1	15.5	18.1	5.1
1967	5.8	5.8	6.4	7.7	14.7	20.9	2.7
1968	2.9	6.0	9.2	9.8	15.4	19.7	0.7
1969	−5.5	1.9	7.0	9.9	16.5	21.0	1.6
1970	0.2	4.2	6.4	7.7	14.3	20.4	2.1.
1971	4.4	4.3	4.7	9.7	15.8	17.4	2.7
1972	1.1	3.0	8.8	8.7	16.1	20.2	2.7
1973	−0.4	3.6	7.7	10.2	16.3	19.4	5.3
1974	−0.9	6.6	8.0	10.9	14.1	21.7	4.8
1975	2.8	3.9	7.3	8.6	15.2	18.8	4.7
Average							
1961-1975	1.4	4.8	7.1	9.7	14.9	19.6	2.5
1935-1960	−0.6	2.8	6.6	10.9	15.0	18.4	2.2

[a]Average monthly temperatures as published in *Local Climatological Data.* Annual Summary, Pendleton, Oregon 1975. National Oceanographic and Atmospheric Administration — Environmental Data Service. National Climatic Center, Asheville, NC. Averages for 1935-1960 and 1961-1975 were calculated from the above.

TABLE 3. The influence of temperature on the latent period of stripe rust. The relationship between temperature and latent period is taken from Shaner and Powelson [1971. Oregon Agric. Exp. Stn. Tech. Bull. 117]

Time period averaged	Average temperature[a] (C)	Latent period (days)
February:		
1935-60	2.8	60-70
1961-75	4.8	37
1961, 67, and 75	5.7	29
April:		
1935-60	10.9	17.4
1961-75	9.7	19.0
1961, 67, and 75	8.8	20.6

[a]*Pendleton, Oregon.*

from March-June. The extremely low precipitation apparently eliminated the existing spring potential for an epiphytotic. A detailed study of how precipitation affects stripe rust epiphytology is underway.

The results of this research provide evidence for climatic variation which has increased the frequency and severity of stripe rust epiphytotics in the Pacific Northwest since 1960. The climatic variation detected at Pendleton, Oregon also occurred throughout Oregon, Washington, and western Idaho. It is probable that a return to colder winters and warmer springs would decrease the frequency and the severity of stripe rust epiphytotics. Because it is impossible to predict what climatic variation will occur, this research has pointed up two important considerations for plant pathologists. The first is that climatic variation should be considered in epidemiological studies of plant diseases which are new in an area or have suddenly increased in frequency or severity. The second is that quantitative measurements of disease losses should be routinely collected to facilitate climatological-plant pathological research.

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