Development of Southern Rust on Maize at Different Stages of Maturity

S. B. KING, Research Plant Pathologist, Agricultural Research Service, U.S. Department of Agriculture and Department of Plant Pathology and Weed Science, Mississippi State University, Mississippi State 39762; and G. E. SCOTT, Research Agronomist, Agricultural Research Service and Department of Agronomy, Mississippi State University

ABSTRACT

King, S. B., and Scott, G. E. 1982. Development of southern rust on maize at different stages of maturity. Plant Disease 66:477-481.

Southern rust caused by *Puccinia polysora* is a potentially serious disease of maize (*Zea mays*) in the United States, particularly on late plantings of maize in the South. This report describes rust severity on leaves of susceptible maize at successive times in the season on plants of staggered planting dates. Susceptibility of lower leaves to *P. polysora* did not vary significantly with maturity of the plant. Although rust severity was generally delayed somewhat in upper leaves, it is believed that this may have been the result of environmental factors rather than resistance to the pathogen per se.

Additional key words: American corn rust, corn

Puccinia polysora Underw., the incitant of southern rust of maize (*Zea mays* L.), was first reported by Underwood (13) in 1896 on a herbarium specimen of *Tripsacum dactyloides* L. collected in Alabama in 1891. Later, Cummins (3) found *P. polysora* on a herbarium specimen of maize collected at least as early as 1879. In addition, he identified *P. polysora* on several other early collections that had been incorrectly identified as *P. sorghi* Schw., the incitant of common rust of maize.

Southern rust is particularly well adapted to a warm, humid environment (2), and it has been reported in most tropical and subtropical maize-growing areas of the world (7,11). The disease caused considerable alarm when it suddenly appeared in West Africa in 1949 and quickly spread across the continent, causing extensive damage in maize in the early 1950s (1,8). In the United States, southern rust is generally considered a minor disease, but it can be destructive in late-planted maize in some years, particularly in the South (4,7,9). In 1979 there were unverified reports of yield losses due to southern rust in Texas and Kansas and spread of *P. polysora* into the corn belt late in the growing season.

Commercially available maize hybrids in the United States show little or no resistance to *P. polysora* (4,9,10), although high levels of resistance to *P. polysora* in the United States have been found (5,12).

At Mississippi State, MS, southern rust usually becomes apparent during the last 2 wk of July or the first week of August. Casual observations of plants of different maturities in experimental plots have given the impression that susceptibility to *P. polysora* may be related to host plant maturity. The purpose of this investigation was to clarify this relationship. Rust severity on leaves of susceptible maize genotypes in various parts of the canopy was estimated at

Contribution of Agricultural Research Service, U.S. Department of Agriculture, in cooperation with the Mississippi Agricultural and Forestry Experiment Station (MAFES). Published with the approval of the Director of MAFES as Paper 4763.

Accepted for publication 10 July 1981.

The publication costs of this article were defrayed in part by page charge payment. This article must therefore be hereby marked "*advertisement*" in accordance with 18 U.S.C. § 1734 solely to indicate this fact.

successive times during the season on plants of staggered planting dates.

MATERIALS AND METHODS

In 1976, rust development was studied on two maize hybrids susceptible to *P. polysora*, B37 × T232 and GT106 × T232. Hybrids were planted nine times at weekly intervals beginning 5 May and ending 30 June. Rust severity was assessed visually 13 times in all plantings at 2- to 5-day intervals from 6 August through 16 September. Rust severity was rated on leaves at three canopy positions: lower leaves (bottom three leaves), middle leaves (ear leaf and two leaves immediately above), and upper leaves (top three leaves).

In 1978, rust development was studied on two different hybrids susceptible to *P. polysora*, B37 × GT106 and GA203 × Mp412, which were planted at four biweekly intervals beginning 11 May and ending 22 June. Rust severity was assessed visually seven times at 4- to 7-day intervals from 5 August through 14 September. Separate rust severity ratings were made on leaves at four canopy positions: lower leaves, ear leaf, leaf midway between the ear leaf and the top leaf, and upper leaves.

Rust severity was measured on a 0–10 scale that was used to estimate the percentage of leaf area covered by uredinia. A rating of 0 indicated that no uredinia were present, and a rating of 10 indicated that 30% or more of the area of the leaf lamina was covered by uredinia. Leaves with a 10 rating were considered 100% infected because there was little or no further increase of uredinia on them before they became completely desiccated. The visual scale used was an interpolation of a key produced by James (6) for rating leaf rust of cereals based on percentage of leaf area covered by uredinia. In both years, test plants were not intentionally inoculated with urediniospores, although plants in adjacent tests in the same field were inoculated during the last week of July. Uredinia from naturally occurring inoculum were first observed at very low levels in early to mid-July on a few plants in other parts of the field.

A split-plot design with planting dates as whole plots and hybrids as the subplots was used. Three replicates were grown, and each whole plot consisted of four rows, two (each 5 m long and 1 m apart) of each hybrid. A single rust severity rating was made for each leaf position for each subplot. To facilitate the comparison of disease development on plants at different stages of maturity, regressions were calculated for rust severity and days after planting and days after urediniospores were introduced into adjacent plots.

RESULTS AND DISCUSSION

In the 1976 test, rust was not observed in plots before 1 August, and severity ratings taken on 6 August indicated that the pathogen was present only in trace amounts. Rust severity became progressively greater during the duration of the experiment until the final evaluation date, 16 September (Table 1). Data obtained later than 116 days after planting have not been included in this report because of the possible negative influence of senescence on infection and uredinial development. Differences in reactions of the two hybrids to *P. polysora* were negligible; therefore, data on the two hybrids were combined for presentation here.

Generally, rust severity on any given date was related to the level of the canopy in which the leaves were located, with lower leaves having the most rust and upper leaves having the least (Table 1). Rust severity on any given day and within a given canopy level, however, was about the same for all planting dates. Exceptions included slightly higher ratings on the lower leaves with planting dates six through eight during August and slightly lower ratings on the middle and upper leaves with planting dates eight and nine through 19 August.

Regressions of rust severity and days after planting (Table 2) and of rust

Table 1. Severity ratings[w] of southern rust at 2- to 5-day intervals on leaves of nine weekly field plantings (5 May to 30 June) of susceptible maize in 1976

Weekly planting[x]	August							September				
	9	11	16	19	24	27	30	3	7	10	13	16
						Lower leaves						
1	1.7[y]	2.4	3.4	4.5	6.1	6.5	6.8	...[z]	...	...	...	...
2	1.7	2.7	2.3	4.7	6.3	6.8	7.6	8.7	...	...	...	...
3	2.0	2.3	3.3	4.2	7.0	7.0	6.7	7.9	9.3	9.9	...	...
4	2.2	2.9	3.4	4.9	6.4	7.2	7.5	8.5	9.5	9.9	10.0	10.0
5	2.0	2.3	3.4	4.7	6.8	6.6	7.0	8.1	8.7	9.5	10.0	10.0
6	2.7	3.7	4.5	5.5	7.1	7.7	8.1	8.6	8.8	9.2	9.9	10.0
7	2.5	4.0	4.5	6.0	7.5	7.8	8.0	8.0	9.0	9.5	9.8	10.0
8	2.3	3.3	3.9	4.7	7.2	7.6	7.7	8.4	9.0	9.5	9.8	10.0
9	1.7	2.4	3.2	3.4	5.6	6.0	6.9	7.6	8.6	9.1	9.3	9.9
						Middle leaves						
1	1.5	2.0	2.8	3.5	5.2	6.9	6.3	...	...	...	...	...
2	1.5	1.9	2.7	4.4	5.0	6.8	7.0	7.8	...	...	...	...
3	1.4	2.2	2.7	4.3	5.7	6.7	6.9	7.3	8.0	9.0	...	...
4	1.9	2.4	3.4	4.4	6.5	6.5	7.5	7.5	9.2	9.3	9.5	10.0
5	1.5	2.4	3.2	4.0	5.8	6.5	7.0	7.7	8.4	9.0	9.7	10.0
6	1.9	2.2	3.0	3.9	5.7	6.5	7.2	8.3	9.0	9.2	9.7	10.0
7	1.4	2.4	2.7	3.5	5.5	6.5	7.0	7.7	8.2	8.2	8.8	9.9
8	1.0	1.7	1.8	2.4	4.5	5.9	6.2	7.7	8.2	8.4	8.9	9.7
9	0.3	1.0	1.0	1.3	5.2	5.9	6.0	7.3	8.5	7.7	8.0	9.2
						Upper leaves						
1	1.0	1.2	1.7	2.7	2.5	3.5	3.7	...	...	...	...	...
2	0.9	1.0	1.7	2.4	2.7	3.5	4.2	6.0	...	...	...	...
3	1.0	1.5	1.7	2.5	2.5	3.5	4.2	5.3	6.2	8.6	...	...
4	1.0	1.4	1.7	2.8	3.0	4.0	4.0	5.4	7.0	9.2	9.0	9.7
5	1.0	1.2	1.5	2.5	3.0	3.5	3.5	5.5	6.0	8.0	8.8	10.0
6	1.0	1.2	1.0	1.4	2.7	3.2	3.0	4.7	5.9	7.2	8.3	10.0
7	1.2	1.0	1.5	1.4	2.5	3.9	4.9	5.3	5.5	6.7	7.9	8.7
8	0.0	0.5	1.2	1.2	1.5	2.5	2.7	5.2	5.3	6.7	7.3	8.3
9	0.0	0.0	0.0	0.0	2.5	3.0	3.5	3.7	5.2	6.0	6.9	7.5

[w] 0–10 scale: 0 = no uredinia, 1 = trace, 2 = 0.5%, 3 = 1.0%, 4 = 2.5%, 5 = 5%, 6 = 10%, 7 = 15%, 8 = 20%, 9 = 25%, and 10 = 30% or more of leaf area covered by uredinia.

[x] First planting on 5 May, first observation of rust on 6 August 1976.

[y] Each datum is average of single severity ratings on each of six subplots, three for each hybrid.

[z] Data omitted because plants were older than 116 days.

severity and days after urediniospores were introduced into adjacent plots (Table 3) were calculated. The regressions are based on the data shown in Table 1. In each case, the predicted number of days to reach a given severity rating of 4 (2.5% of leaf area covered with uredinia) or greater was calculated for leaves in various parts of the plant canopy. Highly significant correlations of $r = 0.95$ or higher ($P = 0.01$) were found between actual and predicted values.

A wide range of plant maturity existed in the experiment during the time disease notes were taken. For example, on 9 August plants of the first planting were at a maturity stage of ca. 3 wk after silking, and plants in the last planting were at a stage of ca. 5 wk before silking. Rust did not appear in plots until early August, and early plantings reached a given rust severity level at a later stage of maturity than later plantings (Table 2). For example, the lower leaves of plants of the first planting date reached a 4 rust severity level 104 days after planting, whereas the ninth planting reached this level 49 days after planting. This difference of 55 days is almost equal to the 8 wk that separated these two planting dates.

A given severity level was usually attained 1–3 days earlier on lower leaves than on middle leaves of the same plants through about the first five planting dates (Table 2). Later plantings seemed to have a greater spread. The top leaves always reached a given severity rating later than the middle leaves. This was eight or more days later, except for planting dates four and five where the difference was about 6 days.

A given severity level was attained on all plantings at about the same time after urediniospores were introduced into the field (Table 3), suggesting that susceptibility of maize is not affected much by maturity. Although plants with the first planting date were not always the first to reach a given severity level in a given part of the canopy, those with the last planting date were always the last. However, for the lower, middle, and upper levels of the canopy, the delay in reaching a given disease severity was never more than 7, 7, and 10 days, respectively. If plant maturity had a large influence on susceptibility, we would expect the first planting to reach a given disease level first and the last planting to reach that same level last, and we would expect a minimum interval of several weeks.

In 1978, four biweekly instead of weekly plantings were used. Rust was first observed during the last week of July, and severity generally increased until the last evaluation in mid-September; however, severity increase was not as steady in 1978 as it was in 1976. This was likely the result of less favorable environmental conditions for rust development in 1978.

Rust data (*not shown*) collected in 1978 were treated the same as the 1976 data, with regressions calculated for rust severity and days after planting (Table 4) and for rust severity and days after urediniospores were introduced into

Table 2. Predicted number of days[w] after planting to reach a given rust severity rating on maize planted in the field at weekly intervals, 5 May to 30 June 1976

Weekly planting[x]	Severity rating[y] 4	5	6	7	8	9	10
			Lower leaves				
1	104	107	111	115	...[z]	...	...
2	97	100	103	107	110	113	...
3	89	93	97	101	105	109	112
4	81	85	89	93	98	102	106
5	75	79	83	88	92	96	100
6	63	68	74	79	84	89	94
7	56	61	66	71	76	81	86
8	52	56	61	66	70	75	79
9	49	53	58	62	67	71	75
			Middle leaves				
1	105	108	113	...	...	...	...
2	98	102	105	109	113	116	...
3	91	95	99	103	108	112	116
4	82	87	91	96	100	104	109
5	76	81	85	90	94	98	103
6	69	74	78	82	86	90	95
7	63	68	72	77	81	86	90
8	59	63	67	71	75	79	83
9	54	58	62	65	69	73	77
			Upper leaves				
1	...	...	...	...	...	...	...
2	106	111	116	...	...	...	...
3	98	103	107	111	116	...	...
4	90	94	98	102	106	110	114
5	84	88	92	96	100	104	108
6	79	83	87	91	95	99	103
7	71	76	81	85	90	94	99
8	67	72	76	80	85	89	93
9	62	66	71	75	80	84	89

[w] Based on calculation of regression of severity and days after planting ($r = 0.95$ or higher, $P = 0.01$).
[x] First planting on 5 May, first observation of rust on 6 August 1976.
[y] 0–10 scale: 4 = 2.5%, 5 = 5%, 6 = 10%, 7 = 15%, 8 = 20%, 9 = 25%, and 10 = 30% or more of leaf area covered by uredinia.
[z] Data omitted because plants were older than 116 days.

Table 3. Predicted number of days[w] after *Puccinia polysora* urediniospores were introduced into the field to reach a given rust severity rating on maize planted in the field at weekly intervals, 5 May to 30 June 1976

Weekly planting[x]	Severity rating[y] 4	5	6	7	8	9	10
			Lower leaves				
1	25	28	32	36	...[z]	...	...
2	25	28	31	35	38	41	...
3	24	28	32	36	40	44	47
4	23	27	31	35	40	44	48
5	24	28	32	37	41	45	50
6	19	24	30	35	40	45	50
7	19	24	29	34	39	44	49
8	22	26	31	36	40	45	49
9	26	30	35	39	44	48	52
			Middle leaves				
1	26	30	34	...	...	...	...
2	26	30	33	37	41	44	...
3	26	30	34	38	43	47	51
4	24	29	33	38	42	46	51
5	25	30	34	39	43	47	52
6	25	29	34	38	42	46	50
7	26	31	35	40	44	49	53
8	29	33	37	41	45	49	53
9	31	35	39	42	46	50	54
			Upper leaves				
1	...	...	...	...	...	...	...
2	34	39	44	...	...	...	...
3	33	38	42	46	51	55	59
4	32	36	40	44	48	52	56
5	33	37	41	45	49	53	57
6	35	39	43	47	51	55	59
7	34	39	44	48	53	58	62
8	37	42	46	50	55	59	63
9	39	43	48	52	57	61	66

[w] Based on calculation of regression of severity and days after urediniospores were introduced into the field ($r = 0.95$ or higher, $P = 0.01$).
[x] First planting on 5 May, first observation of rust on 6 August 1976.
[y] 0–10 scale: 4 = 2.5%, 5 = 5%, 6 = 10%, 7 = 15%, 8 = 20%, 9 = 25%, and 10 = 30% or more of leaf area covered by uredinia.
[z] Data omitted because plants were older than 116 days.

adjacent plots (Table 5). Correlations between actual and predicted values of $r = 0.90$ or higher were found for all values except three, which ranged from 0.77 to 0.79. All correlations were highly significant ($P = 0.01$).

As in 1976, rust developed earlier in plant development in later plantings than in earlier plantings (Table 4). This was especially apparent in the lower leaves and the ear leaf, and it supports the conclusion based on 1976 data that susceptibility to the southern rust pathogen is not dependent on host maturity.

Only minor differences were noted in number of days after urediniospore introduction into adjacent plots among all four planting dates for lower leaves, the first three planting dates for the ear leaf, and the first two planting dates for the leaf positioned midway between the ear leaf and the top leaf (Table 5). A delay in rust development in 1978 was especially noticeable in the ear leaf of the fourth planting and in leaves in the highest two positions of the canopy in the third and fourth plantings. Poor stands that resulted in more widely spaced plants in the third and fourth plantings may have caused some of the delay in rust development in these plantings. Rust severity did not reach a severity level of 4 in the upper leaves of the fourth planting.

It has been reported that maize apparently becomes more susceptible to the southern rust pathogen after silking (10). Our data do not support this view, especially for lower leaves (Tables 1, 3, and 5). For leaves located at higher positions in the canopy, however, we did find evidence of some delay in disease development. Although in our study this delay was not necessarily only associated with the presilking stage, it could be interpreted as evidence for an association of resistance to *P. polysora* with younger leaf tissue. Factors other than resistance per se could also account for the delay in rust development in the upper canopy.

One factor could involve differences in leaf surface microenvironment between the upper and lower parts of the canopy, particularly as it relates to the duration of dew on the leaf surface, a factor crucial to *P. polysora* urediniospore germination and infection (1,2,7). Other factors relating to differences between the upper and lower canopies could involve differences in inoculum concentration and vertical/horizontal leaf habit.

Another factor could relate to the length of time leaves have been available for infection and subsequent disease development. During the presilking growth of the maize plant, new leaves are continually expanding and emerging at the plant apex. Because southern rust requires 9–12 days from infection to uredinial rupture under field conditions, the top leaves of a plant will have had relatively less time for disease development than lower leaves, on which rust could have recycled several times. Furthermore, in making casual observations of rust severity on plants of different ages in adjacent rows, one is likely influenced most by the level of rust on leaves at or slightly below eye level. Hence, in a row that has reached tasseling, evaluations are likely to be based mostly on leaves at ear level or below, leaves that are likely to have the most rust according to our data; whereas a row that is at the pretasseling stage is likely to be evaluated primarily on leaves in the upper part of the plant, leaves that are likely to have the least rust according to our data.

We suggest that susceptibility of maize to *P. polysora* does not vary significantly

Table 4. Predicted number of days[w] after planting to reach a given rust rating on maize planted in the field at biweekly intervals, 11 May to 22 June 1978

Biweekly planting[x]	Severity rating[y]						
	4	5	6	7	8	9	10
				Lower leaves			
1	84	89	95	100	105	110	115
2	76	80	84	89	93	97	102
3	53	58	63	67	73	78	83
4	37	44	50	56	63	69	76
				Ear leaf			
1	85	90	95	100	106	111	116
2	76	81	85	90	95	100	104
3	59	64	69	74	79	84	89
4	54	60	65	71	77	83	88
				Leaf midway between ear and top			
1	92	97	102	106	113	116	...[z]
2	81	85	90	94	99	103	108
3	70	76	83	89	95	101	108
4	77	89	100	112	...	...	...
				Upper leaves			
1	108	116	...	...	...	...	...
2	91	96	102	108	115	...	...
3	85	92	100	108	115	...	...
4	...	...	...	...	...	...	...

[w] Predictions based on calculation of regression of rust severity and days after planting ($r = 0.90$ or higher, $P = 0.01$).
[x] First planting on 11 May, first observation of rust on 5 August 1978.
[y] 0–10 scale: 4 = 2.5%, 5 = 5%, 6 = 10%, 7 = 15%, 8 = 20%, 9 = 25%, and 10 = 30% or more of leaf area covered by uredinia.
[z] Data omitted because plants were either older than 116 days or severity rating was not attained before last evaluation date, 14 September.

Table 5. Predicted number of days[w] after *Puccinia polysora* urediniospores were introduced into the field to reach a given rust severity rating on maize planted in the field at weekly intervals, 11 May to 22 June 1978

Biweekly planting[x]	Severity rating[y]						
	4	5	6	7	8	9	10
				Lower leaves			
1	15	21	26	31	36	41	46
2	21	25	29	34	38	42	47
3	16	21	26	30	36	41	46
4	16	23	29	35	41	48	55
				Ear leaf			
1	16	21	26	32	37	42	47
2	21	26	30	35	40	45	49
3	22	27	32	37	42	47	52
4	23	39	44	50	56	62	67
				Leaf midway between ear and top			
1	23	28	33	37	43	47	52
2	26	30	35	39	44	48	53
3	33	39	46	52	58	64	71
4	56	68	80	91	103	...[z]	...
				Upper leaves			
1	39	47	56	65	74	82	91
2	36	41	47	54	60	65	71
3	48	55	63	71	78	86	94
4	...	...	...	...	...	...	...

[w] Predictions based on calculation of regression of rust severity and days after urediniospores were introduced into the field ($r = 0.90$ or higher, $P = 0.01$).
[x] First planting on 11 May, first observation of rust on 5 August 1978.
[y] 0–10 scale: 4 = 2.5%, 5 = 5%, 6 = 10%, 7 = 15%, 8 = 20%, 9 = 25%, and 10 = 30% or more of leaf area covered by uredinia.
[z] Data omitted because plants were either older than 116 days or severity rating was not attained before last evaluation date, 14 September.

with maturity of the maize plant, at least not after the first several weeks of growth. Our results indicate that upper leaves generally have fewer uredinia than lower leaves, regardless of plant age. However, we believe that this is largely a function of factors other than resistance to *P. polysora*, although a study using controlled inoculations of leaves in various parts of the canopy of the maize plant could further clarify this matter.

LITERATURE CITED

1. Cammack, R. H. 1954. Observations on *Puccinia polysora* Underw. in West Africa. Pages 16-31 in: Annu. Rep. West Afr. Maize Rust Res. Unit, 1st. 1953.
2. Cammack, R. H. 1961. *Puccinia polysora*: A review of some factors affecting the epiphytotic in West Africa. Proc. 1960 Commonw. Mycol. Conf. 6:134-139.
3. Cummins, G. B. 1941. Identity and distribution of three rusts of corn. Phytopathology 31:856-857.
4. Futrell, M. C. 1975. *Puccinia polysora* epidemics on maize associated with cropping practice and genetic homogeneity. Phytopathology 65:1040-1042.
5. Futrell, M. C., Hooker, A. L., and Scott, G. E. 1975. Resistance in maize to corn rust controlled by a single dominant gene. Crop Sci. 15:597-599.
6. James, W. C. 1971. An illustrated series of assessment keys for plant diseases, their preparation and usage. Can. Plant Dis. Surv. 51:39-65.
7. Melching, J. S. 1975. Corn rusts: Types, races, and destructive potential. Pages 90-115 in: Proc. Annu. Corn Sorghum Res. Conf., 30th.
8. Rhind, D. 1954. American maize rust in Africa. World Crops 6:97-98.
9. Rodriguez-Ardon, R., Scott, G. E., and King, S. B. 1980. Maize yield losses caused by southern corn rust. Crop Sci. 20:812-814.
10. Scott, G. E., and Futrell, M. C. 1976. Big epidemic on the way? Southern corn rust. Crops Soils 28:16-18.
11. Shurtleff, M. C., ed. 1973. A Compendium of Corn Diseases. 2nd ed. Am. Phytopathol. Soc., St. Paul, MN. 104 pp.
12. Ullstrup, A. J. 1965. Inheritance and linkage of a gene determining resistance in maize to an American race of *Puccinia polysora*. Phytopathology 55:425-428.
13. Underwood, L. M. 1897. Some new fungi chiefly from Alabama. Bull. Torrey Bot. Club 24:81-86.