Influence of Nutrition on Stalk Rot Development of Zea mays

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ABSTRACT

Breaking strength at 10 days after mid-silk was used as an estimate of inherent stalk strength, which was highest for plants of resistant and susceptible hybrids grown on plots receiving potassium. The hybrid of intermediate resistance to stalk rot had a higher inherent stalk strength in plots receiving nitrogen. Stalk strength decreased late in the growing season.

Symptoms of stalk rot became evident 60 days past mid-silk. Incidence of stalk rot was negatively correlated with stalk strength, and was positively correlated with pith condition ratings. The frequency of rotting was high for the hybrids on all fertilizer treatments on the final observation date. The difference in rotting of stalks grown on nitrogen and no-nitrogen treatments was not significant.

Nitrogen consistently increased the pith condition ratings, and potassium consistently decreased the pith condition ratings 10 days after mid-silk. Both fertilizer treatments reduced the pith condition ratings after frost.

Stalk rot development in plants grown on potassium treatments was reduced at 60 days past mid-silk, but all hybrids were severely rotted by 10 days after the first killing frost. Measurements of stalk strength, pith condition, and natural rotting indicated that stalk rot was delayed in plants grown on potassium-treated plots. Phytopathology 61:1125-1129.

Additional key words: Fusarium moniliforme, Gibberella zeae.

Stalk rot has been recognized as a serious disease of maize since the early 1900's, and currently is considered an important disease of maize in the Midwest (3, 12). Durrell (4), Heald et al. (8), and Burrill & Barrett (2) established that organisms inciting stalk rot weaken the stalks, resulting in breakage late in the growing season. Stalk rot is a disease of the mature plant, with resistance decreasing after pollination (2, 20, 21). It has been suggested that *Fusarium moniliforme* is responsible for the early tissue disintegration in the stalk, which results in a softened rind and eventually a weakened stalk (5). Ikenberry & Foley (10) reported that decline in stalk-breaking strength measurements within hybrids was associated with an increase in high cellulase activity and increased stalk deterioration. They concluded that the stalk tissues were softened and disintegrated by the cellulolytic enzymes produced by *F. moniliforme*.

It has been recognized since 1930 (13) that soil fertility influences stalk rot severity. There is evidence that potassium fertilizers reduce the severity of stalk rot and that nitrogen fertilizers, especially if in excess compared with potash, increase the severity of stalk rot (11, 14, 15, 16, 18, 23). Other factors such as reserve food, structural constituents, and moisture content have been associated with stalk rot resistance (8, 12, 22).

The relationships between stalk rotting and standability are obscure because of the diverse methods used in evaluating stalk rot. The purpose of this investigation was to study the influence of nitrogen and potassium on stalk rot of maize by measuring certain mechanical and physiological properties of three hybrids different in resistance to stalk rot and comparing the measurements made at intervals after mid-silk of each hybrid.

Materials and Methods.—Field plantings of three single-cross hybrids in four replications using a randomized split-plot design were made in 1963 through 1966 either at Ankeny or Ames, Iowa. The hybrids were the main plots, the nutrient applications the subplots. Each hybrid received four treatments: (i) no nitrogen (N) or potassium (K); (ii) 224 kg N/hectare; (iii) 224 kg of K/hectare; and (iv) 224 kg N/hectare plus 224 kg K/hectare. Ammonium nitrate and potassium chloride were the materials used to supply the nutrients tested. Each subplot was six rows, with 40 plants/row in 10-m rows 1 m apart. Three hybrids differing in resistance to stalk rot were used each year. The resistant hybrid was C103 × B14, the susceptible hybrid was L317 × Hy, and both were used all 4 years. The hybrid intermediate in resistance, Wf9 × I205, was used in 1963 and 1964. In 1965 and 1966, Wf9 × A257 was used as the intermediate hybrid.

Stalk samples consisting of the first through the fourth elongated internodes above the brace roots were obtained from each treatment of each cultivar at ca. 10 days, 40 days (1963 and 1964 only), and 60 days after silking in each year. The last sample each year was collected 10 days after the first frost severe enough to kill *Chenopodium album* L. and *Ambrosia* spp. growing in the area adjacent to the maize plants. Ten stalks were taken from the same area within each treatment on the four replicates at each sample date.

Breaking strength and diameter of the second elongated internode were recorded in the laboratory. The breaking strength of the second internode was measured with midpoint loading as described previously

(6). Stalk diameter and rind thickness were measured to the nearest 0.1 mm with a vernier caliper. Pith condition ratings were taken for four internodes by using a method similar to the one described by Pappelis & Smith (17). After the breaking strength of the second internode had been recorded, the stalk was split lengthwise, and the extent of white, dry, spongy-type parenchyma was estimated. The rating scale was as follows: 1 = up to 25% of the internode parenchyma appearing white; 2 = 26-50% of the internode parenchyma appearing white; 3 = 51-75% of the internode parenchyma appearing white; 4 = 76-100% of the internode parenchyma appearing white; and 5 = no green tissue in stalk or leaves, all internode and nodal tissue white.

Natural stalk rot symptoms and corn borer damage were recorded at the time pith condition was rated. Since the plants were not inoculated with any stalk rot organisms, the stalk rot that developed was a result of natural avenues of infection. The stalks were rated as having symptoms if disintegration and (or) mycelial development was observed after the stalks had been split longitudinally and the interior of the nodes and internodes inspected. Stalk breakage was determined at each sample date, and only the stalks broken below the ear were counted. Yields were determined for all treatments each year.

Correlations and an analysis of variance using plot averages were calculated for each of the variables. Two matrices were used: (i) analysis of variance for all dates in 1 year for each year's data; and (ii) analysis of variance combining data of 1964, 1965, and 1966 with analysis for individual sampling dates.

Results.—The significant interactions shown in the analysis of variance i were used to support the interpretations of the data. All differences mentioned in the text are statistically significant unless otherwise stated. The fertilizer treatments were analyzed as a factorial experiment. The main effects of nitrogen and potassium are listed in Table 1 based on the analysis using matrix ii.

Stalk-breaking strength.—The average stalk-breaking strength for the 4 years was 2.07 kg-m at 10 days past mid-silk, 1.61 kg-m at 60 days past mid-silk, and 0.65 kg-m after frost. Stalk strength of all three hybrids decreased with time after mid-silk (Fig. 1). There was a reduction in stalk strength with each progressive time interval after mid-silk for all hybrids, except that in 1965, two hybrids did not show a reduction in stalk strength until after 60 days past mid-silk. Therefore, the measurement at 10 days past mid-silk was considered an estimate of the inherent stalk strength.

Only in 1 year were stalks stronger on the N than no-N treatments; this was using the analysis of variance matrix i, where all sample dates within a given year were assumed to have a homogenous variance for stalk strength. Because there was not a homogenous variance in the stalk strength at all sample dates, the analysis for the individual dates of sampling (matrix ii) was more accurate than the former. When analyzed with matrix ii, differences in stalk strength on N and no-N treatments were not significant (Table 1).

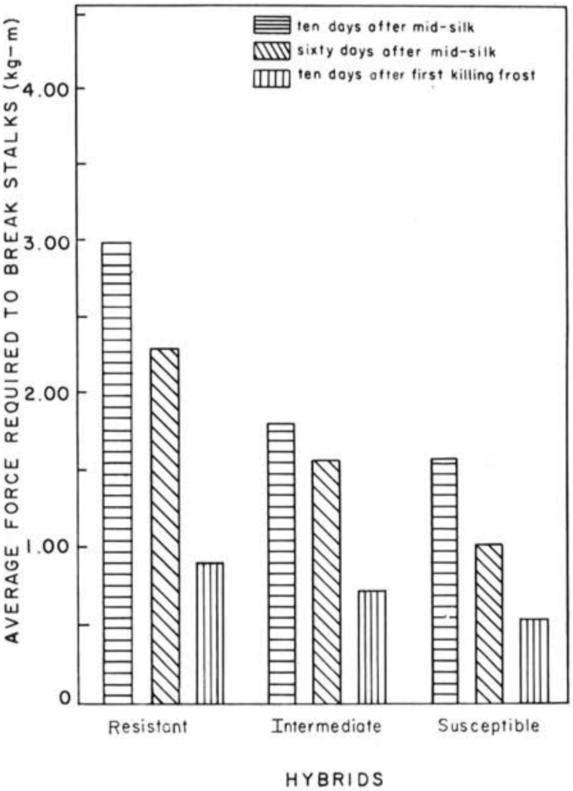

Fig. 1. Four year average of stalk strength (as determined from the second elongated internode above the uppermost brace roots) for three maize hybrids.

Stalks were stronger on K than on no-K treatments 10 days past mid-silk and 60 days past mid-silk. The breaking strength was slightly less after a frost for the stalks grown on K treatments than for those on no-K treatments.

The hybrid intermediate in resistance had a higher stalk strength on N treatments than on no-N treatments, and the stalk strength recorded after frost was higher for plants grown on the N than on no-N treatment only in 1965.

The resistant hybrid, C103 × B14, had the highest stalk-breaking strength at every sample date. The differences in stalk strength between the susceptible and the intermediate hybrids were not consistently different at 60 days after mid-silk and after frost.

Pith condition ratings.—There was an increase in cell death with time after mid-silk of each hybrid. The average pith condition rating of the first elongated internode for the 4 years studied was 0.9 at 10 days past mid-silk, 2.5 at 60 days past mid-silk, and 4.5 after frost. Cell death in the third and fourth elongated internodes had occurred by 10 days after mid-silk in the susceptible hybrid. Therefore, attention was given to the pith condition of the first and second internodes because the parenchyma tissue was viable for a longer period.

Pith condition ratings were lower on the K than no-K treatments at each sample date each year (Table

TABLE 1. Summary of variables of three maize hybrids measured on 3 dates in each of 3 years

Treatment, kg/ha	Stalk strength, kg-m	Stalk diam, cm	Pith[a] condition	Rotted stalk, %	Stalk breakage, %	Yield hliter/ hectare
			10 days after mid-silk			
224 K	2.27	2.42	1.5	0	0	
0 K	2.12	2.34	1.8	0	0	
F value	11.52**[c]	22.59**	31.13**			
224 N	2.18	2.44	1.8	0	0	
0 N	2.22	2.32	1.5	0	0	
F value	N.S.[b]	43.32**	37.38**			
			60 days after mid-silk			
224 K	1.85	2.38	2.7	6.2	1.1	
0 K	1.58	2.30	3.2	8.2	0.4	
F value	14.85**	26.11**	42.33**	N.S.[b]	N.S.	
224 N	1.72	2.40	3.0	8.6	1.3	
0 N	1.71	2.29	2.9	5.8	0.3	
F value	N.S.	46.73**	N.S.	N.S.	N.S.	
			10 days after frost			
224 K	0.65	2.22	4.5	54.0	12.0	87
0 K	0.73	2.21	4.6	52.0	4.0	91
F value	4.48*	N.S.	14.26**	N.S.	30.04*	N.S.
224 N	0.71	2.29	4.5	51.0	10.0	99
0 N	0.67	2.14	4.6	56.0	6.0	80
F value	N.S.	66.06**	16.45**	N.S.	N.S.	75.53**

[a] Average rating of the 2nd elongated internode on a scale of 1 to 5.
[b] Difference not significant.
[c] * = Difference significant at the 5% level. ** = Difference significant at the 1% level.

1), but the differences in the pith condition ratings of the plants from the K and no-K treatments were not significant for each of the three hybrids. At 10 days past mid-silk, only Hy × L317 had sufficient areas of senescent tissue in the lower internodes to have a good estimate of the influence of K on cell death. At 60 days past mid-silk when the three hybrids were nearing final maturation stages, C103 × B14 had lower pith condition ratings on the K treatments. At 10 days after the first killing frost, the pith condition rating interaction of year × K was significant, as was the hybrid × K interaction. C103 × B14 had a lower pith condition rating (higher moisture content) when grown on the potassium treatment. The year × K interaction for the three hybrids was significant for the sample taken after frost.

Pith condition ratings were higher for the plants from N than no-N treatments early in the sampling period, and lower for the plants from N treatments for the sample taken after frost. In all years, the first internode pith condition ratings of the three hybrids was higher for the plants grown on N than on no-N treatments at 10 days past mid-silk. The second internode pith condition rating of the three hybrids was higher for plants grown on N than on no-N treatments, but the differences were not always significant.

By 60 days past mid-silk, there was no significant difference in the pith condition ratings between the plants grown on N and no-N treatments. After a frost, the first and second internode pith condition ratings of the three hybrids were lower for plants on the N than on no-N treatments.

Stalk diameter.—Fertilizer applications influenced diameters of stalks (Table 1). The second elongated internode stalk diameter was larger for all three hybrids grown on the N than on no-N treatments. The largest increase of the three hybrids was for the intermediate hybrid, which had a larger stalk diameter on N treatments than on no-N treatments. The year × N interaction of stalk diameter for samples collected after frost was significant.

The plants grown on K treatments had a larger stalk diameter than the ones grown on no-K treatments at 10 and 60 days past mid-silk, but the difference after frost was not significant. The stalk diameter interaction of hybrid × K was significant only at 10 days after mid-silk, and the resistant hybrid had an increase in stalk diameter on the K treatments.

When the data for the three hybrids were combined, the stalk diameter interaction of N × K was significant at 10 and 60 days past mid-silk. The plants grown on the plots receiving both N and K had the largest stalk diameter, and the plants grown on the check plots had the smallest stalk diameter.

All three hybrids decreased in stalk diameter after mid-silk. The largest decrease occurred after 60 days past mid-silk. The stalk diameter ratio after frost:60 days was 0.94 for all hybrids. Differences in stalk diameter are specific effects for the particular hybrid used, and, in this study, did not have any relationship with the resistant, intermediate, or susceptible characteristics. Stalk diameter did not show a consistent relationship to stalk breakage in maize.

Natural rotting symptoms.—During the 4 years when stalk rotting was investigated, *F. moniliforme* was most frequently identified and *Gibberella zeae* was observed also. *Diplodia zeae* pycnidia were seldom observed; *Nigrospora oryzae* was occasionally present at the last sample date.

Rotting symptoms were detectable 60 days past mid-silk of each hybrid each year. When additional samples were collected at 40 days after mid-silk in 1963 and 1964, none of the three hybrids was noticeably rotted. The percentage of plants with rotting symptoms for the 4 years studied was 7% at 60 days past mid-silk, and 43% after frost.

The differences in percentage of plants with rotting were not always significant among the three hybrids when considered on an individual year basis. The susceptible hybrid had the highest percentage of plants rotted in 1964 and 1965, and the intermediate hybrid usually had a higher percentage of plants rotted than did the resistant hybrid. When the data for 1964, 1965, and 1966 were combined, the percentage of rotted plants was significantly different for the three hybrids.

The N or K treatments did not significantly influence natural rotting at any sample date when the analysis was based on individual sample dates combining the data of 1964, 1965, and 1966 (Table 1). However, the natural rotting interaction of year $\times$ N was significant with a lower percentage in 1964 and a higher percentage in 1966 of rotted plants on the N treatments. From the individual year analysis it was evident that, in addition to the variation observed from year to year, there was a variation in the percentage of plants with natural stalk rotting for the hybrids grown on the N and no-N treatments.

Stalk breakage.—Incidence of stalk breakage was higher in 1965 and 1966 than in 1963 or 1964. The difference in the degree of rotting (as determined by mechanical properties or detectable rotting) of stalks that broke and of stalks that did not break was often small. The percentage of plants rotted was high for every hybrid in 1966, but only the hybrid classified as susceptible had more than 10% broken stalks.

There was some stalk breakage 60 days past mid-silk (1%), but most of the breakage occurred after that. The percentage of stalks broken after frost was 0.4, 4.0, 11.0, and 10.0% in 1963, 1964, 1965, and 1966, respectively. There were, in all 4 years, higher percentages of broken stalks (0.6, 11.0, 30.0, 21.0%) for the hybrid L317 $\times$ Hy than for the other two hybrids (0.0, 0.0, 1.0, 2.0% and 0.6, 0.0, 1.0, 7.0%).

The percentage of stalk breakage was higher for all three hybrids on the K treatments in all years studied, and in 1965 and 1966, the percentage of stalk breakage was significantly higher on the K treatments. Using either matrix i or matrix ii, the percentage of stalk breakage for the resistant hybrid was low each year, and the differences in percentage of broken stalks was not significant on any of the fertilizer treatments. The difference in the percentage of stalks breaking on the N and no-N treatments was not significant any year.

DISCUSSION.—Stalk strength measurements are reported to be good indicators of the resistance of maize to stalk rot, and it was suggested that the rind of the stalk was the most important factor contributing to stalk strength (9, 10, 19, 24). The parenchyma tissue in the pith adds little to the strength of the stalk, but was the site of observable cell deterioration by the stalk-rotting organisms. Pith condition ratings of the internode parenchyma are highly correlated with stalk rot (17). Therefore, the pith condition ratings are also an estimate of the susceptibility of the hybrid to stalk rot. The stalk-breaking strength was an estimate of the inherent mechanical properties of the lower internodes and of the reduction of the inherent mechanical strength due to stalk rot, depending upon when it was measured.

The measurements taken at intervals after mid-silk indicated that the influence of N and K fertilizers on stalk rot of maize was not the same at any given date. Since rotting was not detected at 10 days after mid-silk, and stalk strength did not increase with time each year, the stalk-breaking strength at 10 days past mid-silk was considered the best estimate of inherent stalk strength. The decrease in strength measurements from that of the estimated inherent properties was assumed due to stalk rot, and was an estimate of the degree of rotting.

The ratio of N to K has been reported as an important factor in the incidence and severity of stalk rot (7). The soil fertility of the plots might not have been sufficiently low in N or K to have an N to K ratio such that the incidence and severity of stalk rot was unnaturally accentuated. The yield was increased on the plots that received N applications, but there was not a significant difference in the yields of the K and no-K treatments (Table 1).

Stalk rot severity was reduced when K was applied and increased when N was applied (11, 14, 15, 18). Evidence that high N fertilization was not consistently related to increased stalk rot was that (i) the hybrid intermediate in resistance to stalk rot had a stronger breaking strength on the N treatments; and (ii) the percentage of plants with natural rotting symptoms was not significantly higher on the N treatments. However, evidence that N fertilization may increase stalk rot is that (i) the stalk-breaking strength per cross sectional area was lower on the N treatments than on the no-N treatments at 60 days past mid-silk; and (ii) pith condition ratings at 10 and 60 days past mid-silk were significantly higher for plants grown on N treatments than for plants grown on plots that did not receive N applications.

Evidence that K fertilization reduced stalk rot severity is that (i) potassium increased the stalk-breaking strength of stalks at 60 days past mid-silk; and (ii) K consistently decreased the pith condition ratings. Evidence that K fertilization may increase stalk rot severity is that (i) stalk breakage was significantly higher for the plants grown on the K treatments than for plants grown on plots that did not receive K applications; and (ii) the stalk-breaking strength after frost was significantly higher for the plants on the no-K than on K plots. The breaking strength of plants grown on the K and no-K treatments was sufficiently low to question the importance of the difference, and also indicated that there was extensive rotting on both treatments after frost.

The pith condition ratings were estimates of the percentage of dry, fluffy, white parenchyma per internode. The increase in pith condition ratings with time were indications of the senescence of the pith parenchyma. The increase in pith condition ratings had an inverse relationship to the stalk-breaking strength ($r = -0.9$). The data recorded by Abney (1) in 1965 illustrate the breaking strength and pith condition interrelationship when changes in stalk strength and pith condition rating did not occur as rapidly as observed in other years.

Low pith condition ratings have been interpreted as indicative of the resistance of the plant to stalk rot development. But, late in the growing season, the most rotting was observed in the nodal regions having moist tissue. If resistance to stalk rotting has to do with living intact cells (17), the mechanism for resistance was probably altered or destroyed by the cells of the stalk being subjected to low temperatures. Most hybrids, regardless of resistance, were rotted to some extent, and the plants that had an increase in pith condition rating early in the growing season were ultimately more susceptible to stalk rotting than the plants that maintained dense, well-hydrated parenchyma tissue later into the growing season.

Stalks break because the forces exerted on them exceed their limit of structural strength. Stalk rotting is a factor that reduces structural strength. Stalks are presumed to have a fixed potential for inherent strength, but rotting causes a reduction in strength. The strength measurements were the best estimate of the degree of rotting. Any plant that was severely rotted, as determined by observations of the nodes and internodes, regardless of the hybrid classification to stalk rot resistance, had low stalk strength.

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