Sorghum Downy Mildew Loss Assessment with Near-Isogenic Sorghum Populations

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ABSTRACT

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Three near-isogenic sorghum populations were used to determine the effect of sorghum downy mildew on sorghum grain yields. The near-isogenic populations were developed from the F_3 generation of a cross between the susceptible inbred Tx412 and the resistant inbred SC 414-12. The near-isogenic populations were prepared by mixing equal quantities of seeds from F_3 full-sib families having the same disease reaction classification. The populations were used to evaluate the relationship between downy mildew incidence and grain yields and to provide data to test a previously proposed model of downy mildew yield loss. A significant linear relationship was found between grain yield and downy mildew incidence, and an acceptable level of agreement occurred between measured yields and yields predicted by the downy mildew loss model.

Sorghum downy mildew, caused by *Peronosclerospora sorghi* (Weston & Uppal) Shaw, is an internationally important disease of sorghum (*Sorghum bicolor* (L.) Moench) and corn (*Zea mays* L.) (6). The disease has been reported in 16 states in the United States, but it is of economic importance only in Texas. Downy mildew caused severe damage to sorghum in Texas until it was controlled by hybrids resistant to the disease (6,7).

The appearance of new virulent pathotypes of *P. sorghi* has made many formerly resistant sorghum hybrids vulnerable to the disease (3,4). Metalaxyl, a systemic fungicide effective against *P. sorghi*, is frequently used in areas where the disease is endemic (10). Among the choices available to sorghum growers dealing with downy mildew are the replacement of high-yielding but susceptible sorghum hybrids with a resistant but less productive hybrid; the use of fungicide, which increases the cost of crop production; and replanting or replacing a sorghum crop damaged by the disease. Selection of the most economically desirable option requires the ability to quantify the yield losses caused by sorghum downy mildew.

Tuleen and Frederiksen (12) devised two disease loss models to predict the effect of downy mildew incidence (the number of infected plants as a percentage of the total population) on grain yield in sorghum. The first model was represented by the simple linear equation

$$y = b - (0.00833b)x \quad (1)$$

where y is the predicted grain yield (in kilograms per hectare), b is the expected yield in the absence of the disease, and x is the incidence of downy mildew. The second model was devised for situations in which the plant density per unit area was greater than optimum for grain yield and downy mildew incidence was less than 20%:

$$y = b + (0.00833b)x \quad (2)$$

In the second model, the predicted increase in grain yield associated with an increase in disease incidence is caused by a reduction in the deleterious density of the population. Plants affected by sorghum downy mildew usually die at an early stage of growth.

Tuleen and Frederiksen (12) concluded that the relationship of sorghum downy mildew incidence to grain yield was less than a direct 1:1 ratio because of the beneficial effect of reduced plant competition on the yield of the surviving healthy plants. At the time of their study, neither effective chemical control agents nor isogenic lines were available to evaluate the effects of downy mildew on grain yield in sorghum. To generate data for the model, the researchers used trials in which differences in disease incidence occurred by chance among replicated plantings of sorghum hybrids, and they simulated disease effects by removing plants from trial plots to mimic the results of various incidences of disease on yield and population density.

Trials in which disease levels can be controlled offer a more precise means of disease loss evaluation (9). Burton and Wells (1) devised an effective and relatively quick method of producing near-isogenic populations of pearl millet to study the effects of disease on yield. In their method, resistant and susceptible genotypes were crossed, and plants of each reaction class in the advanced generation were used to form a resistant and a susceptible population. Presumably, the populations had similar gene frequencies for all characters except response to the disease, and any difference in yield between resistant and susceptible populations was attributable to the disease.

This approach seemed applicable to the development of near-isogenic populations of sorghum for evaluation of downy mildew losses. This paper reports the development of three near-isogenic populations of sorghum and their use to test the sorghum downy mildew loss model proposed by Tuleen and Frederiksen (12).

MATERIALS AND METHODS

The parents of the near-isogenic sorghum populations were the sorghum inbred lines Tx412 and SC 414-12. The inbred Tx412 is susceptible to *P. sorghi*, and SC 414-12 is resistant to all pathotypes of *P. sorghi* known in Texas (5). The parental lines were crossed, and the plants in the F_2 generation of this cross were self-pollinated to produce full-sib F_3 families. Resistance to *P. sorghi* in SC 414-12 is conferred by a dominant genetic factor, and the three expected phenotypes of the F_3 families were homogeneous resistant, homogeneous susceptible, and heterogeneous for disease reaction (5).

The reactions of 161 F_3 families to *P. sorghi* were determined by conidial inoculation of a 20-plant sample of each family. With monogenic dominant resistance, the probability of failing to detect heterogeneity with a 20-plant sample is less than 1%. The plants were inoculated at the two-leaf stage of growth by a previously reported technique (2), in which leaves infected with *P. sorghi* were placed above the seedlings under conditions conducive to sporulation of the pathogen. The conidia produced on the infected leaves were distributed over the seedlings by controlled air currents. The inoculated plants were grown in the greenhouse for 6 days and then incubated for 18–20 hr at 20 C and RH above 95%. After incubation, the plants were examined macroscopically for sporulation of *P. sorghi* on the inoculated leaves. The plants on which sporulation occurred were classified as susceptible; plants with no sporulation were classified as resistant (4).

The tested F_3 families were classified as resistant (no susceptible plants in the test sample), susceptible (no resistant plants in the test sample), or intermediate (resistant and susceptible plants in the test sample). In each class, equal quantities of seed from 32 F_3 families were combined to form the resistant, intermediate, and susceptible sorghum populations used in this study. The expected frequencies of susceptible plants in the resistant, intermediate, and susceptible populations were 0, 25, and 100%, respectively.

Trials of the sorghum population were conducted in Honduras in 1983 and Texas in 1984 to evaluate the relationship between the incidence of sorghum downy mildew and grain yields. The trials in Honduras were conducted in 1983 at Las Playitas Agricultural Experiment Station, Comayagua, where downy mildew is endemic, and La Lujosa Agricultural Experiment Station, Choluteca, where the disease does not occur (13). The trial at La Lujosa was conducted to determine if the sorghum populations differed in yielding ability in the absence of downy mildew.

In the Honduran trials, the experimental design was a randomized complete block with three treatments (near-isogenic sorghum populations) and four replications. Each plot consisted of four 5-m rows spaced 0.8 m apart; 3 g of seed was planted per row. The two inner rows of each plot were observed for stand counts and incidence of downy mildew at 3 wk after planting and harvested for grain at 14 wk after planting.

Two trials of the sorghum populations were conducted in 1984 at Beeville, Texas, where sorghum downy mildew is endemic (10,11). One trial was designed to compare the sorghum populations for grain yields in the absence of downy mildew and was planted with seeds treated with metalaxyl, a systemic fungicide effective against *P. sorghi*, at the rate of 1 g a.i. per kilogram of seed (10). The second trial was designed to determine the effect of downy mildew on grain yield, and no fungicidal protection against *P. sorghi* was employed. In both trials, the experimental design was a randomized complete block with three treatments and six replications. Each plot consisted of three 6-m rows spaced 1 m apart; 3 g of seed was planted per row. The center row of each plot was observed for stand count and incidence of downy mildew at 4 wk after planting and harvested for grain at 15 wk after planting.

The results of each trial were analyzed statistically to determine if the sorghum populations were significantly different in stand count, downy mildew incidence, and grain yield calculated in kilograms of grain (at 12% moisture) per hectare. In the two trials in which significant differences in grain yield and disease incidence were found, the data were subjected to simple linear regression analysis.

The y-axis intercepts of the linear regression equations were used as estimates of the grain yields expected in the absence of disease. To test the downy mildew loss model proposed by Tuleen and Frederiksen (12), the estimates of maximum yields and the observed disease incidences were fitted to the loss model, and the regression coefficients derived from the model and those derived from the trials were tested statistically for homogeneity (8).

In another approach to testing the downy mildew loss model, the treatment yields in the trials were expressed as a percentage of the corresponding y-axis intercept (estimated yield in the absence of the disease). The data from the two trials were combined and analyzed for regression of the percentage of maximum yield on disease incidence. The resulting regression coefficient was tested for homogeneity with the regression coefficient of the test model.

RESULTS AND DISCUSSION

The trial at La Lujosa and the trial planted with metalaxyl-treated seed at Beeville tested the hypothesis that the three sorghum populations were equal in yield when downy mildew was absent or the populations were equally affected by the disease. No downy mildew occurred at La Lujosa, and the sorghum populations were not significantly different ($P = 0.05$) in stand count or yield (Table 1). The metalaxyl seed treatment employed in

TABLE 1. Stand counts and grain yields of three near-isogenic sorghum populations in the absence of significant differences in downy mildew incidence

Sorghum population	Beeville, Texas[a]			La Lujosa, Honduras[a]		
	Plants per hectare	Disease (%)	Yield (kg/ha)	Plants per hectare	Disease (%)	Yield (kg/ha)
Resistant	171,667	0.2	1,709	142,500	0	2,062
Intermediate	145,000	3.0	1,845	139,375	0	1,875
Susceptible	178,334	3.0	1,953	138,750	0	1,688

[a]The populations were not significantly different in the number of plants per hectare, the frequency of diseased plants, or grain yield.

the Beeville trial reduced downy mildew incidence but did not completely control the disease. The incidence of downy mildew was 0.2% in the resistant population and 3% in the intermediate and susceptible populations. However, the differences in disease incidence were not statistically significant, and the populations did not differ significantly in yield or stand count (Table 1). The results demonstrated that the sorghum populations met the criteria proposed by Burton and Wells (1) for near-isogenic populations that are suitable for disease loss evaluations.

The near-isogenic sorghum populations exposed to downy mildew in trials at Las Playitas and Beeville differed significantly in downy mildew incidence ($P = 0.01$) and grain yield ($P = 0.05$) but not in stand count (Table 2). The linear regression analysis of relationships between downy mildew incidence and grain yield found significant linear relationships ($P = 0.01$) at Las Playitas and Beeville (Fig. 1). The regression slopes predicted by the Tuleen-Frederikson model were determined by fitting the y-axis intercept estimates (2,036 and 1,421 kg/ha for Beeville and Las Playitas, respectively) to the disease loss model $y = b - (0.00833b)x$. The regression coefficients predicted by the model (−17 and −11.8 kg/ha for Beeville and Las Playitas, respectively) were tested for homogeneity (8) with the regression coefficient estimates of −17.5 and −14.2 kg/ha derived from the trial data of Beeville and Las Playitas, respectively. In each trial, the regression coefficients produced by analysis of the trial data were homogeneous with the coefficients produced by fitting the y-axis intercept estimate of maximum yield and the disease incidences to the disease loss model.

The standardization of yield loss data, achieved by expressing the yield data as a percentage of the maximum grain yield predicted for the trial, permitted data from the two disease loss trials to be combined. The combined data were subjected to regression analysis. The regression slope produced by analysis of the standardized data and that predicted by the Tuleen-Frederiksen model were compared graphically (Fig. 2). The regression coefficient estimated from the standardized data and the coefficient of the model were homogeneous.

There was an acceptable level of agreement between actual yields in the disease loss trials and the yield estimates produced by the disease loss model. However, in our study and in the research reported by Tuleen and Frederiksen (12), the model consistently underestimated the effect of moderate to high incidence of downy mildew on yield. Tuleen and Frederiksen theorized that although downy mildew caused the death or barrenness of diseased plants, the ratio of yield loss to disease incidence was not a direct 1:1 relationship because of decreased competition, with its compensatory benefit for the yield of the surviving plants. However, the magnitude of this compensatory effect is dependent on the spatial distribution of the diseased plants in the field (9). A uniform distribution of infected plants would be more beneficial to the surviving plants than a nonuniform distribution. Recent research by Schuh and co-workers (11) demonstrated that plants infected by *P. sorghi* occurred in clumps rather than being distributed uniformly throughout the field.

These findings suggested that the nonuniformity of distribution of infected plants reduces the expected compensatory effect of reduced competition among the surviving plants and brings the relationship between disease incidence and yield loss closer to a 1:1 ratio than predicted by the model. A second model proposed by Tuleen and Frederiksen (12), for sorghum planted at densities greater than 260,000 plants per hectare and downy mildew incidence of less than 20%, postulated increases in yield due to the disease. This model was not tested in our study. The highest population density observed in the trials was 190,000 plants per hectare, and there was no indication that plant densities were above optimum for the environment. However, the significant beneficial effects of disease-induced reductions in plant density proposed by this second model require uniform distribution of infected plants. If, as indicated by Schuh et al (11), disease distribution is not uniform, the model would overestimate the beneficial effects of the disease on yield.

The equality in yielding ability of the three sorghum populations in the absence of downy mildew (Table 1) demonstrates the desired similarity among the populations for genetic factors affecting yielding ability (1). The occurrence of low frequencies of diseased plants in the resistant population (Table 2) indicates that some susceptible genotypes escaped detection when the F_3 families were tested for disease reaction. However, the tests were accurate enough to produce populations that differed significantly in downy mildew incidence. The results achieved in this study indicate that

TABLE 2. Stand counts and grain yields of three near-isogenic sorghum populations with significant differences in downy mildew incidence

Sorghum population	Beeville, Texas			Las Playitas, Honduras		
	Plants per hectare[a]	Disease (%)[b]	Yield (kg/ha)[c]	Plants per hectare[a]	Disease (%)[b]	Yield (kg/ha)[c]
Resistant	160,000	2	2,087	125,000	3	1,500
Intermediate	153,334	17	1,803	163,000	22	975
Susceptible	190,000	28	1,477	136,250	43	837

[a] No significant differences between the populations.
[b] Differences between populations were significant at $P = 0.01$.
[c] Differences between populations were significant at $P = 0.05$.

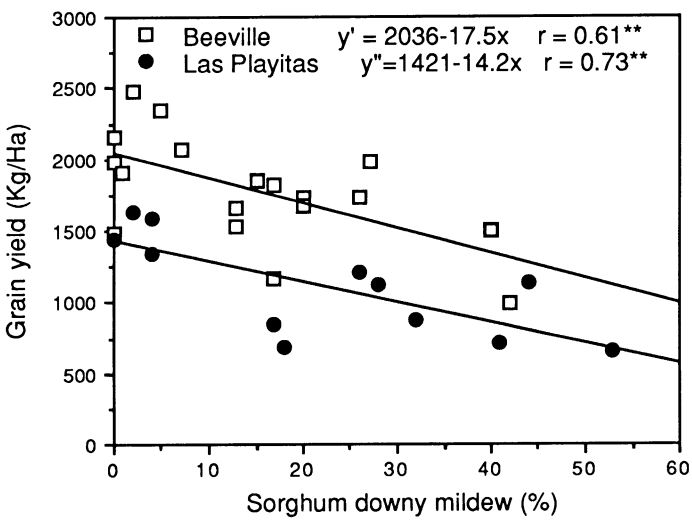

Fig. 1. Relationship of the incidence of sorghum downy mildew to grain yield of sorghum at Beeville, Texas, and Las Playitas, Honduras. ** = Significant linear relationship at $P = 0.01$.

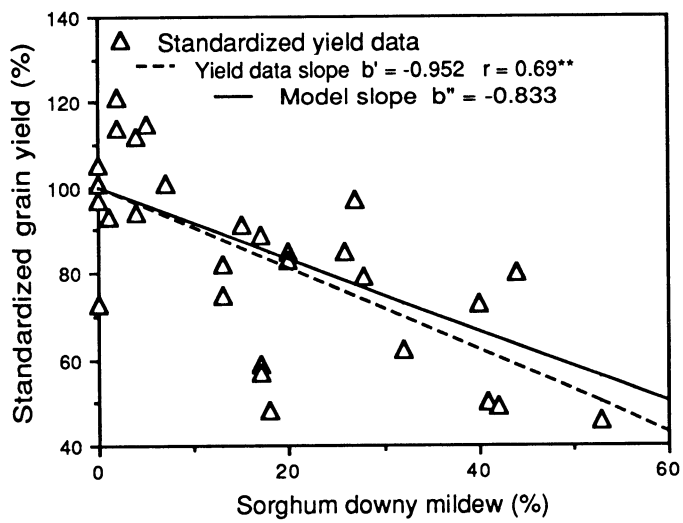

Fig. 2. Relationship of sorghum downy mildew incidence to sorghum grain yields estimated from standardized data (100% at the y intercept) of trials in Honduras and Texas, compared with the relationship predicted by the Tuleen-Frederiksen downy mildew loss model. ** = Significant linear relationship at $P = 0.01$.

near-isogenic populations are an efficient means of determining the effect of this disease on sorghum grain yields.

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