The Influence of Soil Temperature, Soil Moisture, Soil Texture, and Inoculum Density on the Incidence of Sorghum Downy Mildew

W. Schuh, M. J. Jeger, and R. A. Frederiksen

Former graduate student, associate professor, and professor, Department of Plant Pathology and Microbiology, Texas Agricultural Experiment Station, College Station 77843.

Present address of first author: Department of Plant Pathology, Oklahoma State University, Stillwater 74078-0285.

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ABSTRACT

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The incidence of sorghum downy mildew was influenced by combinations of soil moisture-soil temperature, and soil texture-inoculum density. Statistical significance was determined using logistic regression. No significant interaction ($P = 0.05$) was observed within the parameters pairs. A soil temperature-soil moisture combination of 25 C and −0.2 bar and a soil texture-inoculum density combination of 80% sand content and 5 g of oospore powder per 100 g of soil gave the highest disease incidence. The results suggest that soils that are saturated after planting have soil temperatures below 20 C, or sand contents below 20% might be classified as disease suppressive.

Sorghum downy mildew, caused by *Peronosclerospora sorghi* (Weston & Uppal) C. G. Shaw (13), is an important disease of sorghum and maize throughout the tropical and subtropical areas of the world. In the sorghum-growing regions of Texas, soilborne oospores are the major component of inoculum for seedling infection and disease loss (5). Pronounced fluctuations in disease incidence at various locations and over years suggest a strong influence of climate on infection. In particular, soil temperature and soil moisture have been identified as important variables in causing such fluctuations with soilborne plant pathogens (4).

Pratt and Janke (10) demonstrated a strong dependence between inoculum density and soil texture (clay/sand content) on the infection of sorghum by *P. sorghi* under field conditions.

The objectives of this study were to determine and quantify the combined influences of soil temperature and soil moisture, and inoculum density and soil texture, on disease incidence under controlled conditions. The study was initiated to develop a classification system to assess the disease potential of fields, so that growers could make management decisions in selecting control strategies such as cultural controls (15), resistant varieties, and chemical seed treatments (5).

MATERIALS AND METHODS

Soil temperature and soil moisture. The soil used in this experiment was a natural soil (52% sand, 18% silt, and 30% clay). It was steam-treated for 12 hr before use in the experiments.

The effect of temperature on the incidence of sorghum downy mildew was assessed at constant temperatures of 15, 20, 25, 30, and 35 C in Wisconsin-type temperature tanks. The effect of soil moisture was investigated at four moisture regimes for each temperature level (initial moisture level saturated, −0.20 bar, −0.67 bar, −1.00 bar). The soil was adjusted to these matric potentials by determining the soil moisture-release curve (11), spraying with a calculated amount of sterile water, and mixing thoroughly (6). The soils were then placed in plastic bags and left to equilibrate for 48 hr. For each moisture-temperature combination, 12 plastic pots (3-cm square pots × 5-cm height) were filled with soil adjusted to the desired matric potential to a height of 2.5 cm. Ten sorghum (*Sorghum bicolor* L. Moench) seeds (cultivar Pioneer 8515), coated with oospore powder, were placed in each pot and covered with the same soil to a height of 3.8 cm. A 1.2-cm layer of sand was then deposited on top of the soil to reduce moisture loss through evaporation. The oospore powder was obtained by air drying leaves of systemically infected plants, discarding the midrib, grinding the remaining material in a Wiley mill, and sieving through a 200 mesh sieve (75 μm opening). Leaves were collected from systemically infected plants in the previous year and stored in an airtight container in a cold room (6 C). Pots were incorporated into 900-g multipurpose containers filled with moist sand to ensure uniform heat conductivity. The containers were placed in the temperature tanks for 2 wk. In the saturated treatment (Treatment 1), pots were brought up to saturation every 2 days. In the remaining treatments, no water was added during the experiment, thus allowing the soils to gradually dry down. Pots were then transferred to greenhouse benches, where presence or absence of systemic infection was recorded after 14 days on a single plant basis.

Pots were randomly distributed in the temperature tanks. Data were analyzed using logistic regression (SAS Proc Logist), i.e., regressing the probability (in logistic form) of certain disease incidences on the independent variables (8,14). For this purpose, each plant was rated as 0 (= no infection) or 1 (= systemic infection). The data, being of nominal type, were then entered into the logistic regression analysis. Thus, about 2,400 data values (12 pots × 10 seeds × 20 treatments) formed the basis for the statistical analysis. No replication was conducted over time, because logistic regression does not demand or provide for replications.

Inoculum density and soil texture. The soils used in this experiment were natural soils with the following physical properties: Soil A–sand 5%, silt 36%, and clay 59%; Soil B–sand 80%, silt 5%, and clay 15%. Both soils were steam-treated for 12 hr before use in the experiment. Appropriate mixtures of the two soils were blended to obtain soils with sand contents desired for the experiment. Levels of soil temperature and soil moisture were chosen to provide optimal conditions for infection on the basis of results obtained in the soil temperature and soil moisture experiment (−0.20 bar, 25 C). Additionally, the influence of inoculum density on disease incidence was investigated at five different inoculum densities. Quantities of 1, 2, 3, 4, and 5 g of oospore powder, obtained as described above, were added per 100 g of soil and mixed in a rotating drum for 12 hr. The number of oospores per gram of powder was about 220,000. The effect of sand content on disease incidence was assessed with soils of 5% (original soil A), 20%, 40%, 60%, and 80% sand content (original soil B). The

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intermediate levels of sand content were obtained by mixing appropriate amounts of soil A and B in a rotating drum for 12 hr. Square pots of the above dimensions were filled with test soil to a height of 2.5 cm. Ten sorghum seeds (Pioneer 8515) were planted per pot and covered with a 1.3-cm layer of test soil. A layer (1.3 cm) of sand was placed over the soil surface as a cover to reduce moisture loss. Each pot was then inserted into a 900-g multipurpose container as described in the previous experiment. A total of six pots was used per treatment. Pots were left in the temperature tank for 2 wk, then transferred to greenhouse benches for 2 wk, and the total number of plants and systemically infected plants per treatment was determined. The data from the experiment were analyzed as described in the previous section (8,14). About 1,500 data values formed the basis for the statistical analysis.

RESULTS

Soil moisture and soil temperature. The influences of soil temperature and soil moisture on the disease incidence (Fig. 1) were both statistically significant ($P = 0.01$). The best fitting model, as determined through a stepwise procedure, contained the variables soil temperature, soil moisture, and their squared values; the regression coefficient for each variable was statistically significant ($P = 0.01$). The observed optimum temperature for disease incidence was 25 C for all moisture treatments tested, with a maximum incidence value (40%) at −0.20 bar (Fig. 1). No disease occurred at 15 and 35 C. At −0.20 bar the second highest disease incidence was at 20 C, whereas for −0.67 and −1.00 bar it was at 30 C. No disease occurred in the saturated soil treatment at any soil temperature, nor at 20 C in the driest moisture treatment.

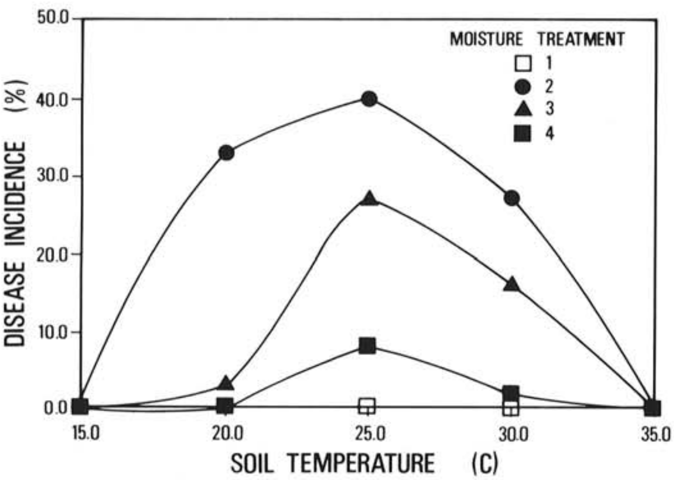

Fig. 1. Influence of five soil temperatures and four soil moisture treatments on the incidence of sorghum downy mildew in the susceptible hybrid cultivar Pioneer 8515. Soil moisture treatment 1 = saturated soil, 2 = initial soil moisture −0.20 bar, 3 = initial soil moisture level −0.67 bar, and 4 = initial soil moisture −1.00 bar.

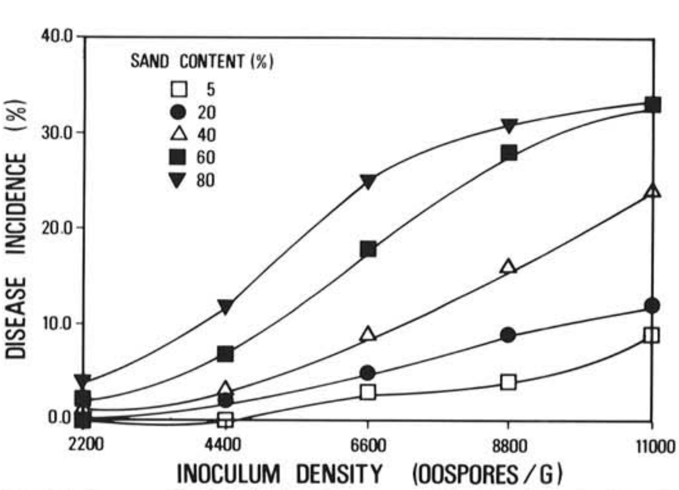

Fig. 2. Influence of five levels of sand content and five inoculum densities of *Peronoscherospora sorghi* on the incidence of sorghum downy mildew using susceptible hybrid cultivar Pioneer 8515.

The interaction between soil moisture and soil temperature was not significant ($P = 0.13$). Their influence on the incidence of downy mildew was about equal when comparing their R statistic (soil moisture = 0.284, soil temperature = 0.287). This R statistic is derived from Akaike's information criterion and related to Mallow's "C" (1,14). Similarly, the squared terms of the independent variables have "R" values of −0.279 and −0.288 for soil temperature and soil moisture, respectively.

The logistic regression model using the parameter estimates obtained through logistic regression can be written as the probability of observing a certain disease incidence for different temperature and soil moisture conditions in this particular soil.

$$\text{Predicted DI (\%)} = 1/(1 + \exp(77.92 - 3.28\,T - 2.45\,M + 0.06\,T^2 + 0.04\,M^2)) \quad (1)$$

where T = temperature in Celsius and M = soil moisture in percent. Partial derivatives of equation 1 were taken, set to zero, solved, and 27.3 C and 31% (−0.20 bar) were determined as optimal soil temperature and soil moisture. Predicted diseases incidences were computed by substituting appropriate values for soil temperature (C) and soil moisture (percent) into equation 1. When comparing these predicted values with the values observed in the experiment, the observed values fell within the confidence interval of the predicted values in 11 out of 20 cases (Table 1).

Soil texture and inoculum density. The influence of soil texture and inoculum density on the incidence of sorghum downy mildew (Fig. 2) was statistically significant ($P = 0.01$). The best fitting model, using a stepwise procedure, contained the variables soil texture, inoculum density, and their squared terms. The interaction between soil texture and inoculum density was not significant ($P = 0.07$). The highest disease incidence of 33% was observed at the combination of 11,000 oospores per gram of soil and a sand content of 60 and 80% (Fig. 2). The disease incidence decreased at lower inoculum densities and sand content. No disease was observed at the combination 5/2,200, 5/4,400, and 20/2,200 of sand content/inoculum density, respectively. The "R"-statistics were similar, 0.104 for inoculum density and 0.108 for soil texture (−0.058 and −0.048 for their squared terms, respectively).

Parameter estimates for the independent variables were computed through logistic regression and used to construct the equation

$$\text{Predicted DI (\%)} = 1/(1 + \exp(7.78 - 0.08I - 0.06\,S + 0.0004\,I^2\ 0.0004\,S^2)) \quad (2)$$

where I is the inoculum density and S is the sand content in percent.

Partial derivatives of equation 2 were taken, set to zero, solved, and 11,000 oospores per gram of soil and a sand content of 75% were determined as optimal inoculum density and sand content.

Predicted disease incidences were computed by substituting appropriate values for inoculum density (oospores per gram of soil) and sand content into equation 2. When comparing these predicted values with the values observed in the experiment, the observed values fell within the confidence interval of the predicted values in all cases (Table 2).

DISCUSSION

The inhibitory effect of high soil moisture on the incidence of sorghum downy mildew corroborates the findings of Pratt (9) and Balasubramanian (3). Pratt (9) found a significant reduction in the germination rate of oospores when containers were watered daily for 4 days (after planting) and an absence of oospore germination when soil cups were watered daily for 20 days. The influence of temperature was not investigated. Balasubraminian (3) in field

TABLE 1. Comparison of observed and predicted incidence of sorghum downy mildew for Pioneer 8515 hybrid: The influence of soil temperature and soil moisture

Soil temperature	Soil moisture treatment[a]											
	1			2			3			4		
	Obs	Pred[b]	CI[b]	Obs	Pred	CI	Obs	Pred	CI	Obs	Pred	CI
15 C	0[c]	0	0/0	0	0	0/0	0	0	0/0	0	0	0/0
20 C	0	3	9/1	33	18	27/13	3	12	19/8	0	0	1/0
25 C	0	12	23/5	40	61	69/52	27	49	58/40	8	3	7/1
30 C	0	3	7/1	27	29	38/22	16	20	28/15	2	1	2/0
35 C	0	0	0/0	0	0	2/0	0	0	1/0	0	0	0/0

[a] Soil moisture treatments were 1 = saturated soil; 2 = initial soil moisture −0.20 bar; 3 = initial soil moisture −0.67 bar; and 4 = initial soil moisture −1.00 bar.
[b] Predicted values, 95% confidence interval (CI) (upper and lower values) computed through equation 1 (see text).
[c] Mean of 120 plants.

TABLE 2. Comparison of observed and predicted incidences of sorghum downy mildew for Pioneer 8515 hybrid: The influence of soil texture and inoculum density

Inoculum[a] density	Soil texture (% sand content)														
	5%			20%			40%			60%			80%		
	Obs	Pred[b]	CI[b]	Obs	Pred	CI	Obs	Pred	CI	Obs	Pred	CI	Obs	Pred	CI
2,200	0[c]	0	0/0	0	0	1/0	1	1	3/0	2	2	5/1	4	3	7/1
4,400	0	1	0/2	2	2	3/0	3	4	7/3	7	8	11/5	12	10	14/7
6,600	3	2	4/1	5	5	7/3	9	10	14/8	18	17	22/13	25	21	28/15
8,800	4	4	7/2	9	8	12/6	16	17	22/13	28	27	33/22	31	32	39/25
11,000	9	5	9/3	12	11	15/7	24	0	28/16	33	32	40/25	33	38	47/29

[a] Oospores per gram of soil.
[b] Predicted values, 95% confidence interval (CI) (upper and lower values) computed through equation 2 (see text).
[c] Mean of 60 plants.

experiments determined that a range of 76–79% available soil moisture suppressed disease incidence. In the present study, sorghum downy mildew did not occur in the saturated soil treatment whatever the temperature. According to Balasubramanian (3), available soil moisture in the range 44–47% is optimal for disease expression. The influence of low soil moisture was not investigated by either author. Incidence of sorghum downy mildew clearly declines with drier soils, once the optimum soil moisture is passed. Optimum soil temperatures are necessary at unfavorable soil moisture conditions for infection to occur. This could be interpreted as a infection phenomena similar to the situation described by Aust and Hau (2) for *Septoria nodorum*. Conversion of available soil moisture (3) to matric potential is not possible, thereby preventing more comparison of the data.

The significant influence of soil temperature, with a temperature optimum of about 25 C, is in agreement with the results of Balasubramanian (3) and Kenneth (7). Balasubramanian (3) determined the optimal temperature to be 26.3 C, with a considerable reduction in disease incidence at 21.3 C. Kenneth (7) found the optimum temperature for infection of a sorghum×sudan hybrid in Wisconsin-type tanks to be between 24–29 C. The range in which infection occurred was 22–32 C. No infection occurred at temperatures less than or equal to 20 C. Those results are similar to the ones obtained in this study; the optimum soil temperature was 27 C, with no infection observed below 20 C and above 30 C.

Equation 1 (Table 1) overestimated the influence of the favorable soil temperature range (20–30 C), and underestimated the suppressive effect of saturated soil. In the temperature range of 20–30 C, disease incidence was overestimated for the initial moisture levels of saturated, −0.20 and −0.67 bars; and underestimated for moisture level −1.00 bar and the soil temperature, soil moisture combination 20 C/−0.20 bar.

There were statistically significant influences of inoculum density and soil texture on disease incidence. Even though the interaction was statistically not significant at $P = 0.05$, the existence of such interaction should be kept in mind since it was significant at $P = 0.07$. Under field conditions, this interaction could have a significant influence on disease incidence. Pratt and Janke (10) obtained similar results in field trials. They observed no correlation of inoculum density with disease incidence, unless soil texture or sand content was considered, in which case a high correlation was obtained. Similar results were observed in this study. Even in 11,000 oospores per gram of soil, disease incidence was only 9% at 5% sand content, whereas an incidence of 12% was observed for 4,400 oospores per gram of soil at the 80%-sand-content treatment. At all inoculum densities, disease incidence was greater as the sand content increased or clay content decreased.

There is a strong likelihood that soil texture and soil moisture and their effects on soil pathogens are correlated as has been demonstrated for Fusarium wilts (4). Ideally a four-factorial experiment is required to assess the influence of all four factors and their possible interactions. Pratt (9) determined that less than 1% of the oospores in their samples were infective. Because the oospores used in their experiment differed, in all probability, in their characteristics such as age, storage conditions, etc., from the oospore population used in this experiment, this value cannot be applied to this study, but should nevertheless be acknowledged.

The results from this study could be used to classify fields for their disease potential, solely based on the knowledge of sand content and climatic conditions during planting. Fields with soil temperatures of less than 20 C, and/or a predominance of saturated or dry soils in the first 2 wk after planting, could be considered to have low or no potential for sorghum downy mildew. This was substantiated by a Principal Component Analysis of weather data (12). More detailed experiments are needed before recommendations could be given to growers.

Soil conditions unfavorable for infection are fairly common early in the sorghum-planting season in the Coastal Bend region of Texas. Planting as early as possible, therefore, should help suppress the incidence of sorghum downy mildew. Additionally, early planting is desirable from an entomological and agronomical viewpoint.

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