Epidemiology and Yield Losses Associated with Alternaria Blight of Sunflower

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ABSTRACT

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Epidemics of Alternaria blight, caused by *Alternaria helianthi*, were initiated at different plant growth stages on two sunflower genotypes (cms HA89 and hybrid 894) during the 1981 and 1982 growing seasons at Brookings, SD. Yield losses as great as 51 and 60% were observed on hybrid 894 and cms HA89, respectively, when seed yields were compared to those of check plots sprayed with fungicide. The 100-seed weights and seed oil contents were also significantly reduced in some inoculated treatments. Yield losses, losses in 100-seed weight, and oil content were consistently greater on the inbred line cms HA89 than hybrid 894, indicating that Alternaria could be a greater problem in seed production fields than in commercial hybrid fields. The logistic growth model consistently fit Alternaria blight progress curves better than the Gompertz model in 1981, but in 1982 no consistent difference between the models was detected. Selected critical-point, and multiple-point regression yield loss models gave coefficients of determination of 0.65 and 0.70, respectively, when disease severity was used to predict percent yield reduction due to *A. helianthi*.

Additional key words: *Helianthus annuus*, yield loss assessment.

Alternaria blight of sunflower, caused by *Alternaria helianthi* (Hansf.) Tubaki and Nishihara has been recognized as a potentially destructive disease in India, Yugoslavia, Australia, Tanganyika, Uganda, and South Africa (5–7,9,16,17,22,23). In the United States, Alternaria blight has been particularly destructive on sunflower in Ohio, Florida, and Mississippi, and has been reported from Minnesota, North and South Dakota, and Wisconsin (12,15,18,20,21). *A. helianthi* can cause severe leaf and stem spots resulting in premature defoliation and stem breakage. In addition, a seedling blight due to *A. helianthi* has also been reported (20). Estimates of yield losses in sunflower due to Alternaria blight in India range upward to 80% (2,6,7,10,14,17). The disease significantly reduces head diameters, numbers of seeds produced per head, 1,000-seed weight, and percent oil content of seed (6,7,10,17). Disease severity is negatively correlated with yields ($r = -0.76$ and -0.62 for two cultivars, respectively) (6). Estimates of yield losses due to Alternaria blight of sunflower at two locations in Australia in the 1977–1978 growing season were 26 and 17%, respectively (5). Thousand-seed weights were significantly reduced by Alternaria blight at both sites, and percent oil content was significantly reduced at one site.

Although destructive levels of Alternaria blight have been reported in the warmer, more humid areas of the United States (12,18,21), no information is available on the potential

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destructiveness of this disease on adult plants in the principal sunflower production region of the United States, the Minnesota-Dakotas region. Because the pathogen appears to be able to infect sunflower over a wide range of temperatures (3,4), is seedborne (12), and apparently is expanding its range in the United States, information on the potential threat of this pathogen to domestic sunflower production is needed.

The objectives of these experiments were to determine the effect of varying levels of Alternaria blight severity on sunflower seed yields, seed weight, and oil content under conditions typical of much of the primary sunflower production area of the United States, and to determine the relationship between disease severity at different sunflower growth stages and yield.

MATERIALS AND METHODS

Yield loss studies were conducted during the 1981 and 1982 growing seasons on the South Dakota State University Plant Science Department Research Farm at Brookings. The experimental design consisted of a 2 × 5 factorial combination of sunflower genotypes and inoculation treatments in a randomized complete block design with four replications. The two sunflower genotypes were the female inbred line cms HA89 and the USDA hybrid 894 (cms HA89 × RHA 274). Inoculation treatments consisted of a fungicide sprayed check and four growth stages (19) at the time of initial inoculation; V1 stage (vegetative stage with one pair of fully expanded true leaves), V6 stage (vegetative stage with six true leaves at least 4 cm long), R1 stage (early reproductive stage with young inflorescence in the "star" stage), and R5 stage (beginning of anthesis). Experimental units consisted of four rows 6.1 m long and 1 m apart. Plots were hand planted with 30 seeds per row during the first week of June both years. Only the two center rows received inoculation (or fungicide) treatments and were harvested.

All plants in the center rows of each plot were artificially inoculated with *A. helianthi* by placing 20–30 grains of a sterilized barley or sorghum grain culture of *A. helianthi* onto the uppermost leaves at the proper growth stage. A plot was determined to be at the proper growth stage (V1, V6, R1, or R5) when the majority of plants in the plot were judged to be at the correct stage of development. The V1, V6, and R1 inoculation treatments were also inoculated a second time on the subsequent inoculation date to ensure adequate disease development. The R5 inoculation treatment was inoculated only once. Fungicide check plots were sprayed weekly from the V6 growth stage to the R8 growth stage with a mixture of mancozeb (Dithane M-45 80% WP formulation of a coordination product of zinc ion and manganese ethylene bisdithiocarbamate, 1.8 kg a.i./ha) and benomyl (Benlate 50% WP formulation of methyl-1-(butylcarbamoyl)-2-benzimidazole carbamate, 0.3 kg a.i./ha) in 1 L of water per plot using a hand-held sprayer.

Plots were visually rated weekly for percent leaf area infected from 21 July to 8 September by using the Horsfall-Barratt scale (13), and for plant growth stage (19). Ratings were converted with the Elanco conversion tables (Eli Lilly and Co., Indianapolis, IN). Plots were hand-harvested, threshed, and plot yields were recorded. Data on 100-seed weights and percent oil content of seeds were also taken. Oil contents were measured by using nuclear magnetic resonance and were adjusted for percent seed moisture. Data were analyzed statistically and Fisher's Least Significance Difference ($P \leq 0.05$) was used to test differences among treatment means. Percent yield reductions were calculated by comparing inoculation treatment mean yields with those of the fungicide-treated check plots. The relationship between disease severity ratings and yield losses were determined by use of simple regression (criticial-point model) techniques and multiple regression (multiple-point models) using the maximum R^2 improvement model fitting technique (SAS Institute Inc., Raleigh, NC). Infection rates for each disease progress curve were calculated by regressing logit and gompit transformed proportions of disease against time in order to compare the suitability of the two transformations in linearizing Alternaria blight curves.

RESULTS

Alternaria blight significantly reduced sunflower seed yields of both hybrid 894 and cms HA89 in both 1981 and 1982 (Table 1). Losses were as great as 60% in 1981 and as great as 49% in 1982. The greatest yield losses consistently occurred in plots where epidemics were initiated at the V6 growth stage. The inbred line cms HA89 generally sustained greater yield reductions than hybrid 894. One-hundred-seed weights were also significantly reduced by Alternaria blight on both genotypes in both years. Seed weight losses were generally greater on cms HA89 than hybrid 894. Seed yield losses were significantly negatively correlated with 100-seed weights ($r = -0.76$, $P \leq 0.05$) in 1981.

Percent oil content of seeds was also significantly reduced on both genotypes in 1981, but not in 1982. This reduction was greater on cms HA89 than hybrid 894, and was significantly negatively correlated with seed yield losses ($r = -0.67$, $P \leq 0.05$) in 1981.

Severe disease developed on both hybrid 894 and cms HA89 in 1981 (Fig. 1). Disease severity in excess of 90% was observed at the R9 growth stage (crop at physiological maturity) on cms HA89 initially inoculated at the V6 stage and was greater than 60% at maturity on all inoculated treatments. Final disease severities were greater on both hybrid 894 and cms HA89 when initially inoculated at the V6 and R1 stages than when initially inoculated at the earlier (V1) stage (Fig. 1A and B). Disease development was not as great in 1982; final disease severities at crop maturity never exceeded 70% and were greater than 50% only for those epidemics initiated at the V1 and V6 growth stages (Fig. 1C and D). Effective disease control

TABLE 1. Effect of leaf blight epidemics caused by *Alternaria helianthi* initiated at different plant growth stages on seed yields, 100-seed weights, and oil percentage of sunflower hybrid 894 and inbred line cmsHA89. Data are from 1981 and 1982, and were collected at the Plant Science Farm, Brookings, SD

		1981				1982			
Genotype	Growth stage at inoculation[a]	Yield (kg/ha)	Yield loss (%)	100-Seed weight (g)	Oil (%)	Yield (kg/ha)	Yield loss (%)	100-Seed weight	Oil (%)
Hybrid 894	V1	1,263	41	4.05	41.37	2,311	17	4.39	41.18
	V6	1,064	51	3.81	41.21	2,195	21	4.01	42.72
	R1	1,928	10	4.12	42.52	2,296	17	4.54	41.90
	R5	1,777	17	4.36	41.50	2,511	9	4.63	41.90
	Check	2,152	0	4.85	42.86	2,769	0	4.98	42.54
cmsHA89	V1	495	31	3.33	42.79	866	24	4.45	45.17
	V6	284	60	3.55	42.26	582	49	3.89	44.16
	R1	656	8	3.76	45.45	622	45	3.71	44.74
	R5	754	−5	4.48	44.59	960	16	4.65	46.16
	Check	715	0	5.07	46.31	1,138	0	5.25	46.12
FLSD ($P = 0.05$)		275		0.65	1.54	371		0.57	2.50

[a]Growth stages are according to the system of Schneiter and Miller (19).

was obtained in the fungicide-sprayed check plots in both years; final disease severities never exceeded 12%.

Estimates of apparent infection rates for the Alternaria blight epidemics varied from 0.0686 to 0.1310 and from 0.0224 to 0.0603 when disease progress data from inoculated plots were fitted to logistic and Gompertz models, respectively (Table 2). Logistic infection rates in 1981 were consistently higher on cms HA89 than on hybrid 894. Also, logistic infection rates in 1981 were consistently higher with epidemics initiated at later growth stages when compared to those initiated at earlier stages. In 1982, logistic

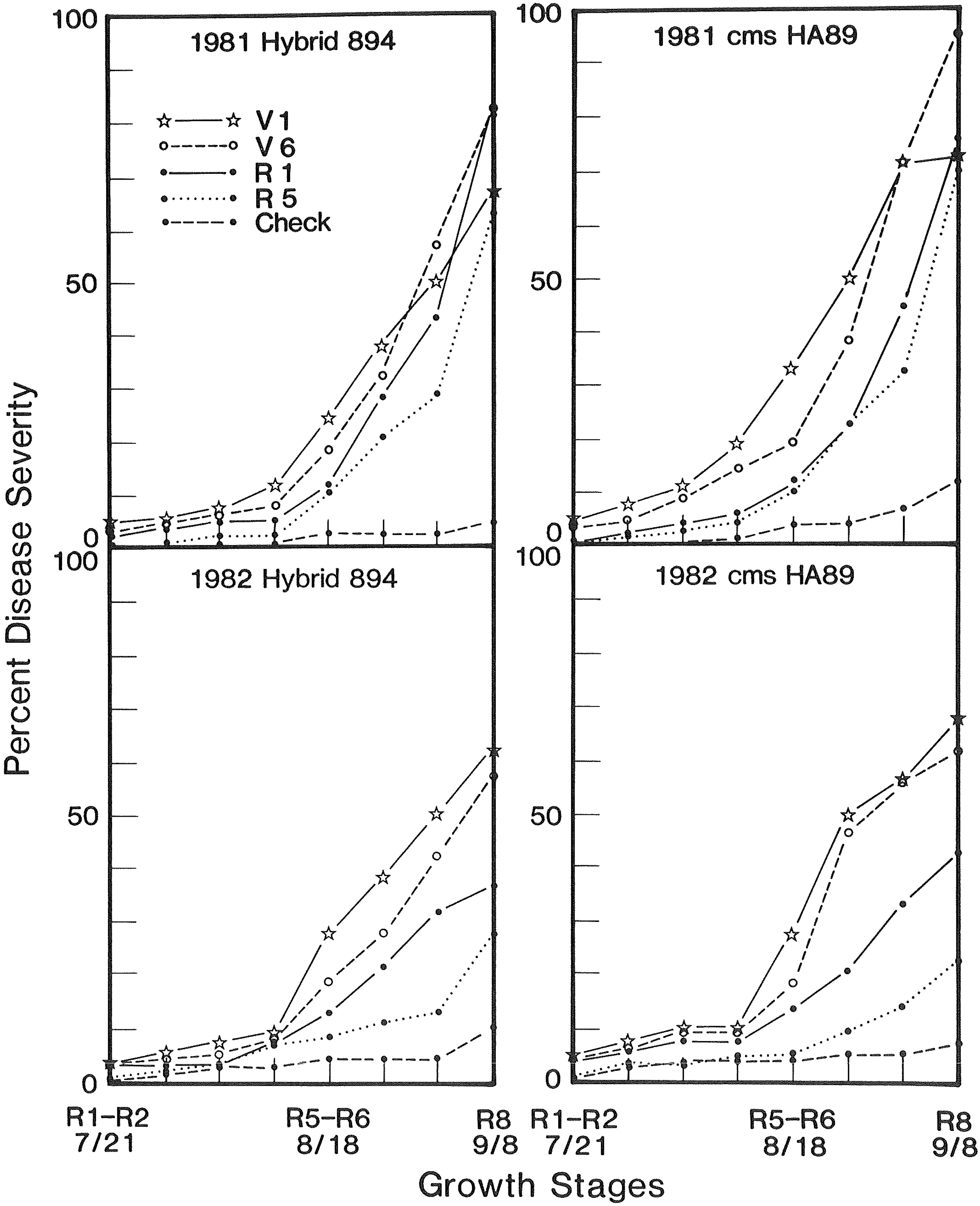

Fig. 1. Alternaria blight progress curves for two sunflower genotypes (Hybrid 894 and cms HA89) inoculated at growth stages V1, V6, R1, and R5 (19), and fungicide-sprayed check plots during the 1981 and 1982 growing seasons.

infection rates did not follow this pattern. Using the Gompertz infection rates, epidemics initiated at the V6 growth stage proceeded at the fastest rates on both genotypes in both years. In 1981, the data consistently fit the logistic growth model better than the Gompertz model (i.e., produced a higher coefficient of determination, r^2). The 1982 epidemics fit both models about equally well, with all coefficients of determination equal to or in excess of 0.93.

The goodness-of-fit of critical-point regression models to predict yield losses to Alternaria blight based on disease severity varied depending on the sunflower genotype, the year, and the growth stage at which disease severity was rated (Table 3). In 1981, disease severity at the R3–R4 (4 August) and R2–R3 (28 July) growth stages were the best predictors of yield losses on hybrid 894 and cms HA89, respectively. When 1981 data from both genotypes is included in the model, disease severity assessed at the R2–R3 (28 July) growth stage was the best predictor of yield losses, accounting for 61% of the variation in yield losses. Disease severity assessed at the R1–R2 (21 July) and R9 (8 September) growth stages were the best predictors of yield loss on hybrid 894 and cms HA89, respectively, in 1982. The best predictor of yield loss on both genotypes was disease severity at the R2–R3 (28 July) growth stage in 1982. When the data were combined over genotypes and years, 65% of the variations in yield loss could be accounted for by disease severity at the R3–R4 (4 August) growth stage. Disease severity at the R8 stage (1 September) was about equal in its value as a predictor of yield loss, accounting for 64% of the variability. When maximum R^2 improvement was used to fit the combined data to a model, the two-variable model that included disease severities assessed at the R2–R3 and R8 growth stages gave the best fit ($R^2 = 0.70$) and still produced partial correlation coefficients that were significant at the 10% level of probability. Selected single-point equations and the one multiple regression equation to predict sunflower yield loss from disease severities are presented in Table 4. Examination of residuals from selected models revealed no consistent pattern, indicating that transformation of the data was not warranted.

TABLE 2. Disease progress rates and coefficients of determination (r^2) of 16 epidemics of Alternaria blight of sunflower calculated by fitting the data to two growth models[a]

Year	Genotype	Growth stage at initial inoculation	Logistic model Rate	Logistic model r^2	Gompertz model Rate	Gompertz model r^2
1981	Hybrid 894	V1	0.0856	0.99	0.0437	0.95
		V6	0.1054	0.97	0.0552	0.88
		R1	0.1088	0.93	0.0538	0.82
		R5	0.1181	0.96	0.0523	0.94
	cms HA89	V1	0.0950	0.99	0.0534	0.96
		V6	0.1220	0.93	0.0742	0.80
		R1	0.1238	0.98	0.0603	0.89
		R5	0.1310	0.98	0.0573	0.92
1982	Hybrid 894	V1	0.0845	0.99	0.0390	0.96
		V6	0.0890	0.98	0.0435	0.97
		R1	0.0792	0.95	0.0317	0.95
		R5	0.0717	0.95	0.0245	0.96
	cms HA89	V1	0.0702	0.99	0.0305	0.97
		V6	0.0926	0.97	0.0476	0.95
		R1	0.0886	0.98	0.0440	0.95
		R5	0.0686	0.93	0.0224	0.94

[a] Model equations were $y = 1/(1 + \exp(-[a + rt]))$ for the logistic model and $y = \exp(-B\exp(-kt))$ for the Gompertz, in which r and k represent the rate parameters for logistic and Gompertz models, respectively.

DISCUSSION

Alternaria blight is a potentially devastating disease that could seriously affect production in the principal sunflower-growing areas of the United States. The yield losses of up to 60% in these experiments demonstrate that *A. helianthi* is capable of causing substantial losses under environmental conditions prevalent in the Minnesota-Dakotas region. These loss estimates are comparable to those reported from India under conditions of natural infection (2,6–8,14,17). Although *A. helianthi* has caused isolated losses as a seedling blight in Minnesota (20), this is the first report of potential losses on mature sunflower in this area. A major effect of Alternaria blight appeared to be on the 100-seed-weight component of yield, although head diameters were not recorded as in other studies (5–7,17). The reduction in seed oil content caused by Alternaria blight is also of economic concern, because growers receive a price premium or a dockage based on oil content. Greater yield losses sustained by the commercially important female parent inbred line cms HA89 compared to hybrid 894 indicate that the potential for losses is perhaps greater in hybrid sunflower seed production fields than in commercial hybrid fields. Control of this disease in hybrid seed production fields is also critical because of the seedborne nature of the pathogen (12). Perhaps the hybrid vigor of hybrid 894 is partially responsible for the lower losses it sustained compared to cms HA89.

The generally better fit of the Alternaria blight epidemics to the logistic model compared to the Gompertz is in contrast with the findings of Berger (8), who found that the Gompertz growth model usually fit better. Both models, however, fit the data reasonably well in most instances, and these findings are not conclusive as to the superiority of either model. Both models are effective (8) in linearizing symmetrical and assymmetrical disease progress curves when disease severities are between 0.05 and 0.60. Most of the

TABLE 3. Coefficients of determination (r^2) of critical-point regression models[a] predicting percent yield loss (Y) from Alternaria blight severities ($0 \leq X \leq 1.0$) assessed at different plant growth stages[b] during the 1981 and 1982 growing seasons on two sunflower genotypes

		Independent variable (disease severity X at a particular growth stage)							
Year	Genotype	X(R1–R2)[c]	X(R2–R3)	X(R3–R4)	X(R4–R5)	X(R5–R6)	X(R7)	X(R8)	X(R9)
1981	Hybrid 894	0.59	0.56	0.87*[d]	0.75†	0.81*	0.66†	0.70†	0.43
	cms HA89	0.61	0.70†	0.64	0.62	0.37	0.46	0.66†	0.38
	Both	0.60**	0.61**	0.60**	0.54*	0.47*	0.50*	0.60**	0.36†
1982	Hybrid 894	0.95**	0.74†	0.46	0.74†	0.77†	0.85*	0.89*	0.87*
	cms HA89	0.77†	0.93**	0.85*	0.87*	0.86*	0.93**	0.96**	0.98**
	Both	0.57*	0.82**	0.77**	0.58*	0.55*	0.79**	0.76**	0.72**
1981 and 1982	Hybrid 894	0.54*	0.36*	0.58*	0.45*	0.48*	0.60**	0.65**	0.54*
	cms HA89	0.67**	0.77**	0.71**	0.53*	0.50*	0.58*	0.62**	0.35†
	Both	0.58**	0.61**	0.65**	0.51**	0.49**	0.59**	0.64**	0.42**

[a] Models were simple regression models in which: Y (percent yield reduction) $= a + bX$ (disease severity).
[b] Sunflower growth stages are according to the system of Schneiter and Miller (19).
[c] (R1–R2), etc., indicate that plants were about equally divided between those at each growth stage, and were judged to be in transition between the two stages.
[d] †, *, and ** indicate the regression coefficient (slope) of the fitted model is significantly different from zero at the 0.10, 0.05, and 0.01 levels of probability, respectively.

Alternaria blight severity data recorded in these experiments were in this range, and the small difference in the fit of the two models is not unexpected. Also, Alternaria blight progress curves were calculated with only eight values each and in some instances disease development had already begun before assessment started. For reliable estimates of epidemic parameters to be obtained, estimation should begin early in the epidemics, and be done at short intervals so that the number of values used in estimation exceeds 20 (8).

The success in prediction of sunflower yield losses due to Alternaria blight with critical-point regression models was dependent upon the plant growth stage at which disease severity was assessed, the host genotype, and the year in which the epidemics were studied. Although certain critical-point models fit the data from a single genotype in a single year quite well (for example, with cms HA89 assessed at the R9 stage in 1982, 98% of the variation in yield loss could be explained by disease severity) the utility of such models is questionable. When all the data were fitted to critical-point models, lower fits were obtained and their precision declined. The inclusion of additional independent variables (disease severities) into the model by using the maximum R^2 improvement technique, produced only a slight increase in R^2 for the "best" two-variable model. All subsequent models fitted (three or more independent variables) resulted in some or all partial regression coefficients becoming statistically nonsignificant ($P > 0.10$).

To be of practical value, yield loss prediction models must not only be reasonably precise, but should also be simple to use, be applicable to a wide range of host genotypes, and fit a wide range of epidemics with differing disease progress curves. Some of the critical-point models developed in these experiments do meet the criteria of precision and simplicity, but are not applicable to a wide array of either sunflower genotypes or disease progress curves. Others (those from the combined data) are again simple to use and are applicable to a number of disease progress curves, but are lacking in precision. The correlation coefficients of Alternaria blight and yield found in these experiments are, however, higher than those reported by others (6,18). Twenty different disease progress curves (four replications each) were produced by using two genotypes inoculated at different growth stages in two divergent growing seasons. The addition of data from many more Alternaria blight epidemics will be needed before a more precise multiple-point model can be developed. Data from additional epidemics probably would not increase the fit of critical-point models that would be applicable to a wide array of sunflower genotypes or disease progress curves. The high coefficients of variation of sunflower seed yields in these experiments (15 and 7% for 1981 and 1982, respectively), typical of many sunflower yield trials, as well as the use of subjective visual disease severity assessments make the development of more precise models using these methods difficult. Prediction of losses, however imprecise, is probably best done by assessing disease severity at the R3–R4 growth stage (if using the single-point model) or at the R2–R3 and R8 stages (if using the two-point model). Disease severity should be assessed at as many representative points in the field as is practically feasible, and the average used in the prediction equations.

Alternaria blight will continue to be a serious potential problem for sunflower production throughout the world until adequate control measures are developed. Although fungicides gave excellent control of Alternaria blight in these experiments, the expense, number of sprays required, and the difficulty of achieving adequate spray coverage of sunflower foliage may well make chemical control unfeasible at this time. Survival of *A. helianthi* in crop residues (3) and in seed (11) as well as the presence of alternate hosts (3) may well make crop rotation an ineffective control measure. Although a greenhouse study (15) indicated that resistance to *A. helianthi* may only be found in a few perennial species collections in the USDA Helianthus Collection, other studies of Alternaria blight in the field indicate some resistance in *H. annuus* expressed as a reduction in percent leaf area infected (1,11,18). The development and exploitation of genetic resistance in *H. annuus* is probably the best way to reduce the threat of Alternaria blight to sunflower production.

TABLE 4. Selected critical-point and multiple-point regression equations to predict percent yield losses in sunflower due to Alternaria blight based on disease severity ($0 \leqslant X \leqslant 1$) assessed at different plant growth stages (R1 to R9)[a]

Year(s)	Genotype	Equations	Coefficient of determination (R^2)[b]
1981	Hybrid 894	−2.27 + 678.5 (X R3–R4)	0.87
	cms HA89	−2.38 + 860.4 (X R2–R3)	0.70
	Both	3.34 + 810.1 (X R2–R3)	0.61
1982	Hybrid 894	1.00 + 772.2 (X R1–R2)	0.95
	cms HA89	−6.28 + 80.5 (X R8)	0.98
	Both	−2.26 + 96.2 (X R7)	0.79
1981 and 1982	Hybrid 894	−3.84 + 67.8 (X R7)	0.65
	cms HA89	−5.65 + 915.7 (X R2–R3)	0.77
	Both (single-point)	−3.29 + 476.2 (X R3–R4)	0.65
	Both (multiple-point)	−5.85 + 408.2[b] (X R2–R3) + 42.4 (X R7)	0.70

[a]Growth stages are according to the system of Schneiter and Miller (19).
[b]Partial regression coefficients in the multiple-point model were significant at the $P = 0.10$ level of probability.

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