Frequency and Timing of Fungicide Applications for the Control of Gray Leaf Spot in Maize

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ABSTRACT

Ward, J. M. J., Laing, M. D., and Rijkenberg, F. H. J. 1997. Frequency and timing of fungicide applications for the control of gray leaf spot in maize. *Plant Dis.* 81:41-48.

Timing and frequency of fungicide treatments for management and control of gray leaf spot of maize, caused by *Cercospora zeae-maydis*, were quantified with the logistic model and area under disease progress curve (AUDPC). Control was most effective when spraying commenced as disease severity levels reached 2 to 3% of the leaf area blighted and when lesions were restricted to the basal five leaves of the maize plant. Highest grain yields were achieved with treatments providing disease control until the crop was physiologically mature. To provide this length of control, the frequency and number of fungicide applications varied with the stage of host development when disease was first apparent; with early infections, more fungicide treatments were necessary to provide protection until physiological maturity. Yield responses to fungicides appeared to be a function of the growth stage of the host when sprays were initiated, the amount of disease at spray date, the length of fungicide control, and effective control through to physiological maturity.

Few diseases of major crops have risen from relative obscurity to general recognition as a threat to economical production as suddenly as has gray leaf spot (GLS) of maize (*Zea mays* L.). GLS is caused by the fungus *Cercospora zeae-maydis* Tehon & E. Y. Daniels (10). The disease was first observed in 1988 in KwaZulu-Natal, South Africa, and has since spread rapidly throughout the higher rainfall and irrigated areas of the province. In these areas, it is estimated that 60% of the commercial crop grown is affected by GLS (14). The pathogen has more recently been observed in major maize-growing areas of neighboring provinces in areas of lower rainfall. This is of great concern to the maize industry. Trials conducted at Cedara Agricultural Development Institute (CADI) near Pietermaritzburg, South Africa, have shown that the disease is capable of reducing grain yields by 20 to 60% depending on hybrid susceptibility to *C. zeae-maydis* (13). Fungicides can provide excellent control of the pathogen (13).

Disease progress for GLS is, in general, best described by the logistic model. Progress curves linking the transformed disease severity data points enable the examination of the effects of fungicide treatments on

disease progress. Application of an effective fungicide to foliage interrupts progress of a disease soon after spraying and lasts for an "effective period." This fungicide effective period (FEP) is defined as that period, after application of the fungicide, during which there is minimal disease increase. The FEP is measured from disease progress curves of the transformed data of each treatment, starting from the time of fungicide application and ending when there is a sharp increase in disease progress (3). This definition differs slightly from the description by Berger (3), who suggested that the treatment effect of a protectant fungicide starts one latent period after spraying, because latent infections are not controlled by protectant fungicides. The discrepancy arises because systemic fungicides, used in this study, control all infections, including latent infections. Characteristics of the theoretical response to fungicide treatment are the sharpness of the swing of the disease into the FEP, zero disease increase during the effective period, and the parallelism of disease progress to the nontreated control (the epidemic delay is equal to the FEP at all subsequent times after the FEP). The FEP is a function of fungicide efficiency, its dose, and the residual breakdown curve (3). With systemic fungicides, the FEP is longer and the disease increase during the FEP is less than with protectant fungicides (3). In practice, when host growth is minimal, which is usual with GLS, as it attacks maize near anthesis, the FEP has a slight upward slant of increasing disease because the fungicide is unable to provide complete control of

the pathogen (3). The level of disease severity at the time of fungicide treatment affects subsequent disease progress. If disease severity is high at the time of application, the rate of disease increase into FEP is more gradual, the FEP has a steeper slope (greater disease increase), and the FEP is shorter (3). At higher levels of disease, the infection efficiency becomes lower because there is less healthy tissue available for infection, although more inoculum may be present.

This investigation was undertaken to establish the most effective time of application of fungicides and the frequency of sprays necessary for effective control of GLS until physiological maturity.

MATERIALS AND METHODS

Field study. The study was conducted between 1991 and 1994 at CADI, (29° 32'S, 30°17'E) situated 15 km north of Pietermaritzburg at an altitude of 1,070 m. The site was north facing and gently sloping, and consisted of well-drained, deep, sandy-clay, loam soils of the Hutton form and Doveton series (8). The trial area had been continuously cropped to maize for the previous 10 years.

The trials were conducted on the same field over the three seasons. The field was no-till seeded into the previous season's maize debris at a seeding rate of 50,000 seeds ha⁻¹ with a John Deere 7000 Max-Emerg 4-row planter. Four experiments were planted: on 31 October and 6 December 1991; 5 November 1992; and 26 October 1993. Final plant stands were 45,000 plants ha⁻¹. Fertilizer was applied at a rate sufficient for an 8-ton ha⁻¹ grain crop based on soil analyses and recommendations by the Cedara Fertilizer Advisory Service. Fertilizer was band applied at planting to supply 32 kg of N, 48 kg of P, 63 kg of K, and 2.4 kg of Zn ha⁻¹. Limestone ammonium nitrate was broadcast when maize was knee-high to provide a further 97 kg of N ha⁻¹.

A tank-mix of metolachlor (1.86 kg ai ha⁻¹) plus atrazine/metolachlor/terbuthylazine (550/633/550 g ai ha⁻¹) in 300 liters of water ha⁻¹ was applied as a pre-emergent herbicide treatment for the control of grasses and broadleaf weeds. Fenvalerate (28 g ai ha⁻¹) was included in the herbicide tank-mix for the control of cutworm. Carbofuran granules (2.7 kg ai ha⁻¹) were ap-

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Accepted for publication 15 August 1996.

plied in the planting furrow for the control of soil insect pests.

Two experiments conducted in the 1991 to 1992 season were split-plot design with four replications. Time of fungicide application was the main plot with hybrids as subplot treatments. Fungicides were applied as single-spray applications made prior to, at, and after anthesis, 53, 67, 89,

and 103 days after planting (DAP) in the early planted experiment, and 53, 67, 78, and 90 DAP in the late planted experiment. Two hybrids were planted, National Seeds RS 5206 and Carnia's CRN 4526. RS 5206, previously widely grown in Kwa-Zulu-Natal, is considered to be highly susceptible to GLS, while CRN 4526 is less susceptible. Following results from the

1991 to 1992 experiments, the trial design in the 1992 to 1993 and 1993 to 1994 seasons was changed to a randomized complete block design and only hybrid RS 5206 was used. Treatments consisted of single- and multiple-spray applications. The timing of the sprays commenced at different levels of disease; sprays were initiated when lesions were present on the

Fig. 1. Standard assessment diagrams for evaluation of gray leaf spot lesion area on maize. (Percentages given represent the amount of leaf area affected and are indicated by the darkened portion of the leaf).

basal two leaves, on the basal five leaves, on all basal leaves to ear-height, and on all basal leaves to above ear-height.

Plots consisted of eight rows, spaced 750 mm apart, and were 12 m long. Fungicide spray solutions were applied to the four central rows, and the central 10 m of the two middle rows of the treated area were assessed for disease and harvested for grain yield. The fungicide used in 1991 to 1992 was benomyl at a rate of 375 g ai ha⁻¹ (Benlate 50% WP, Du Pont de Nemours and Coy). In the first season, it was applied in 1,500 liters ha⁻¹ water at 0.15 kPa pressure with a hand-operated Cooper-Peglar back-pack sprayer fitted with a lance and single Spraying Systems TeeJet No 8001 nozzle. In subsequent seasons, a combination of 187.50 g of carbendazim plus 93.75 g of flusilazole ai ha⁻¹ was applied (Punch Xtra, Du Pont de Nemours and Coy) in 500 liters of water, with a CO₂-pressurized back-pack sprayer with a vertically mounted spray-boom having three Whirlrain 1/4" WRW2 - 20° nozzles spaced 1 m apart.

The dehusked ears from the central two rows of the trial unit were weighed in the field. Subsamples of five or six ears were weighed and shelled in the laboratory, and the shelling percentage determined to calculate the shelled grain mass for each. Moisture content of a 250-g sample of shelled grain was determined and the grain yield was adjusted to 12.5% moisture content.

Disease assessment. Kranz (7) and Campbell and Madden (4) stressed the importance of standard assessment diagrams as training tools and as guides to improve accuracy and precision in disease assessment. Standard diagrams were developed, based on the standard area diagrams by Smith (10). Leaves of a commonly grown maize hybrid at silking were numbered 1 to 17 for each leaf position from the bottom to the top of the plant. Surface area of each leaf for each leaf position of 20 plants was measured with a LI-COR LI-3100 Area Meter and surface area of an average leaf area for each position was established. Plants in the field showing GLS were examined, starting when only leaves 1 and 2 exhibited visible lesions. These were matched against Smith's standard area diagrams and the percent diseased tissue for each leaf was determined. Calculations with these data and the average surface area for the corresponding leaf position were used to establish the area of diseased tissue, as a percentage of the whole plant. The procedure was repeated as the disease developed on leaves 3, 4, and 5, and progressively more leaves acropetally, until the entire plant exhibited GLS symptoms. Standard assessment diagrams showing 2, 5, 10, 20, 35, and 50% disease were constructed and used as a guide in estimating disease severity (Fig. 1). These data were used to calculate the area under disease progress curve (AUDPC).

The AUDPC, a summary of the disease epidemic, was used for treatment comparisons and was calculated from data based on the trapezoidal integration program (2). For making comparisons between epidemics of different time durations, the AUDPC was standardized by dividing the AUDPC value by the total time (days) duration of the epidemic (6).

Statistical analysis. The disease severity data was transformed to fit the logistic model described by Vanderplank (12) and Gompertz (2) in order to linearize the progress curve, thereby allowing treatment comparisons, and the measurements of infection rate and FEP. Disease progress, except for the 1991 to 1992 season, was best described by the Vanderplank model (based on comparisons of coefficients of determination [R^2]), and this model was used in this study. Disease severity, AUDPC, infection rate (r), FEP, and grain yield were analyzed by analysis of variance. Mean separations were based

on Duncan's multiple range test at the 5% level of probability. The analysis was conducted on Genstat 5, version 2.2, Rothamstead Experiment Station, Harpenden, U.K.

RESULTS

GLS was not observed at CADI prior to the 1991 to 1992 season and inoculum levels in situ were assumed to be relatively low. However, inoculum from debris from the previous crop was sufficient to initiate GLS epidemics in subsequent seasons. GLS was first observed on 4 February, 4 January, and 16 December in the 1991 to 1992, the 1992 to 1993, and the 1993 to 1994 seasons, respectively. Anthesis was observed 89 and 77 DAP in the 1991 to 1992 experiments and 80 and 78 DAP in the 1992 to 1993 and 1993 to 1994 experiments, respectively. Physiological maturity in these experiments occurred 150, 150, 149, and 153 DAP, respectively.

Table 1. Conditions at Cedara for the maize growing seasons 1991 to 1994

Condition	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Total
Rainfall (mm)								
1991 to 1992	209	198	149	105	120	95	51	927
1992 to 1993	34	83	69	69	108	115	25	503
1993 to 1994	133	68	162	206	127	113	37	846
Average	125	116	126	158	130	102	32	789
Mean temperature (°C)								
1991 to 1992	16.1	18.3	19.7	20.4	21.0	19.8	18.9	
1992 to 1993	17.7	18.5	20.3	21.0	20.0	19.4	17.3	
1993 to 1994	17.0	18.3	19.4	19.9	19.4	19.0	17.1	
Average	17.1	18.4	19.9	20.6	20.4	19.2	17.6	

Table 2. Gray leaf spot (GLS) disease development and grain yield of two maize hybrids for fungicide treatments applied at different dates after planting (DAP)¹

Hybrid/ treatment date	Fungicide applied (DAP)	Disease severity (%) ^u				Grain yield (kg ha ⁻¹)
		Assessment (DAP)			SAUDPC ^w	
		121	134	<i>r</i> ^v		
RS 5206 ^x						
Nonsprayed	...	22 a ^y	91 a	28.4 a	56 a	6,177 b
23 December	53	24 a	86 a	23.5 a	55 a	5,898 b
6 January	67	4 b	55 b	27.8 a	30 b	8,480 a
28 January	89	1 b	16 c	24.0 a	9 c	9,689 a
11 February	103	2 b	5 d	6.3 b	4 c	8,686 a
Mean						7,786 ^z
CRN 452 ^x						
Nonsprayed	...	16 c	91 a	31.6 c	54 e	3,557 c
23 December	53	16 c	85 a	27.6 c	51 e	3,875 bc
6 January	67	3 d	50 b	27.3 c	27 f	4,575 b
28 January	89	1 d	13 c	21.2 d	7 g	4,838 a
11 February	103	4 d	2 d	4.1 e	3 g	5,360 a
Mean						4,441 ^z
SE (of a mean)		1.5	3.3	3.0	1.8	363.8
Grand mean		9.5	49.6	21.4	29.5	6,113
CV %		22.0	9.0	19.2	10.5	11.6

¹ Planted 31 October 1991.

^a Disease severity is percent leaf tissue with symptoms of GLS.

^v Infection rate $\times$ 100, calculated by regressing the logistic transformation on time (DAP).

^w Standardized area under disease progress curve.

^x Anthesis occurred 89 days after planting.

^y Means within a column having letters in common do not differ significantly ($P < 0.05$) according to Duncan's multiple range test.

^z The grain yield of RS 5206 was significantly greater ($P < 0.001$) than that of CRN 4526.

Weather conditions varied over the seasons in which trials were conducted (Table 1). Growing conditions in 1991 to 1992 were warm and moist during the vegetative growth stages of maize but, after anthesis, rainfall declined. During grainfill, days were warm to hot and heavy dews favoring disease were frequent. The 1992 to 1993 season was dry, with only 63% of the average rainfall recorded during the growing season. In contrast, the rainfall in 1993 to 1994 was above average and well distributed throughout the growing season. Temperatures were lower than average during grainfill and mists were frequent, especially during January and February 1994.

1991 to 1992 season. Disease was first observed in the early and late planted experiments 95 and 60 DAP, respectively. The fungicide treatments applied soon after disease was first observed in both plantings, on 11 February, provided among the most effective control of disease (AUDPC) and among the highest grain yields (Tables 2 and 3). As a result of more disease observations in the late planted experiment (6 December 1991), presentation of additional results is confined to this experiment (Table 3).

Initial disease progress was slow, with disease severity of nonsprayed treatments increasing in the first 26 days from 1 to 8% in RS 5206 and from 1 to 3% in CRN 4526. Subsequent progress was rapid: disease severity increased in the following 30 days from 8 to 88% in RS 5206 and from 3 to 80% in CRN 4526 (Table 3).

Although there was on average higher disease (AUDPC) for RS 5206 than for CRN 4526, RS 5206 had on average higher grain yields (6,480 kg ha⁻¹) than CRN 4526 (5,384 kg ha⁻¹) (Table 3). There was lower disease (AUDPC) with fungicide treatments of both hybrids than with the nonsprayed treatments, and this was reflected in highly significant grain yield responses to fungicides. The fungicide treatment initiated on 11 February, 7 days after disease was first observed, had the lowest disease (AUDPC = 19) and the longest FEP (39 days) in RS 5206, and had among the lowest disease (AUDPC = 16) and longest FEP (32 days) in CRN 4526. This treatment, 67 DAP, also had the highest grain yields in both hybrids although these were not significantly different from those with fungicide treatments applied later.

The fungicide treatment applied at 53 DAP, 2 weeks before disease was observed, had higher final disease severity, higher AUDPC, higher infection rate, shorter FEP, and lower grain yield than the fungicide treatment applied at 67 DAP. Treatment later, at 90 DAP, when there was relatively higher final disease severity, also had higher AUDPC and shorter FEP, and, with CRN 4526, had lower grain yield than treatment at 67 DAP (Table 3).

1992 to 1993 season. Despite unfavorable weather conditions for disease during the vegetative growth stage of the crop, GLS symptoms were observed before an-

thesis, 60 DAP. Initial disease development was slow, with disease in the nonsprayed treatment rising to 7.8% severity 36 days after first symptoms were observed. Subsequent progress was rapid, with severity increasing to 60% in the following 21 days (Table 4).

All fungicide treatments provided significant reduction in disease (AUDPC) and reduced the infection rate (Table 4). Fungicides provided effective control of disease up to 118 DAP, but did not provide control through to physiological maturity at 149 DAP. Disease progress following the FEP was normal and paralleled that in the nonsprayed treatment (Fig. 2B). Multiple-spray treatments resulted in longer FEP (41 to 52 days) than single-spray treatments (26 to 33 days). The spray treatment initiated at 83 DAP; when the basal five leaves of the host were symptomatic, provided the longest FEP (33 days) of the single-spray treatments.

1993 to 1994 season. Climatic conditions were favorable for GLS and disease was first observed earlier (53 DAP) than in the previous season (60 DAP). Disease progress followed a trend similar to that in previous seasons, with initial slow disease progress (up to 2% disease in 40 days) followed by rapid progress, reaching 71% severity in the following 36 days.

All fungicide treatments reduced disease severity, by 147 DAP, shortly before the crop was physiologically mature (Table 5). Fungicides also reduced overall disease

Table 3. Gray leaf spot (GLS) disease development, effective periods of fungicide control, and grain yields of two maize hybrids, for fungicide treatments applied at different dates after planting (DAP)^p

Hybrid/ treatment date	Fungic. appl. (DAP)	At treat- ment date ^q	Disease severity (%) ^r				SAUDPC ^s	<i>r</i> ^t	<i>R</i> ^{2u}	Effective period		Grain yield (kg ha ⁻¹)
			Assessment (DAP)							Length in days ^v	Period end (DAP)	
			86	99	116	140						
RS 5206 ^w												
Nonsprayed	...		8	55 a ^x	88 a	100 a	68 a	13.1 a	0.977	...		4,101 c
28 January	53	0	1	33 b	73 b	99 a	58 b	15.9 a	0.961	14 c	63	5,524 b
11 February	67	1.5	2	1 c	5 e	69 bc	19 c	9.8 b	0.827	39 a	104	7,929 a
21 February	78	5.7	5	18 c	16 d	83 ab	28 d	8.8 b	0.878	26 b	104	7,770 a
6 March	90	21.5	10	42 b	35 c	63 c	34 d	4.5 c	0.752	17 c	107	7,075 a
Mean							42 ^y					6,480 ^z
CRN 4526 ^w												
Nonsprayed	...		3	49 d	80 f	100 d	63 d	14.1 e	0.966	...		3,463 f
28 January	53	0	1	14 f	56 g	100 d	50 c	16.6 f	0.997	15 e	59	5,177 e
11 February	67	0.5	2	1 g	3 i	64 e	16 b	8.8 h	0.879	32 d	99	6,551 d
21 February	78	2.1	2	4 g	10 i	71 e	21 ab	8.8 gh	0.976	25 d	104	6,364 d
6 March	90	9.8	6	35 e	25 h	56 e	27 a	4.6 g	0.846	17 e	107	5,387 e
Mean							36 ^y					5,384 ^z
SE (of a mean)				3.0	3.6	5.3	2.5	1.6		2.4		280.6
Grand mean				23.9	39.0	80.4	38.6	11.4		23.1		5,932
CV %				13.6	7.8	5.5	5.4	26.8		16.0		8.7

^p Planted 6 December 1991.

^q Disease severity from logistic progress curves.

^r Disease severity is percent leaf tissue with symptoms of GLS.

^s Standardized area under disease progress curve.

^t Infection rate $\times$ 100, calculated by regressing the logistic transformation on time (DAP).

^u Coefficient of determination.

^v Calculated from logistic progress curves.

^w Disease first observed 60 DAP, anthesis occurred 77 DAP, and physiological maturity at 150 DAP

^x Means within a column having letters in common do not differ significantly ($P \leq 0.05$) according to Duncan's multiple range test.

^y AUDPC values for RS 5206 and CRN 4526 were significantly ($P < 0.001$) different.

^z Grain yield of RS 5206 was significantly higher than that of CRN 4526 ($P < 0.001$).

(AUDPC) for all treatments, except the single-spray treatment 2 (beginning 88 DAP when lesions were present on the basal two leaves), compared with the non-sprayed treatment. The reduction in disease by fungicide treatment was reflected in significant grain yield responses.

Time of application and number of spray treatments under conditions favorable for disease development in 1993 to 1994 contributed to large differences in disease severity, length of the FEP, and grain yields harvested. The three-spray and two-spray programs, except for treatment 8 (beginning at higher initial disease severity, 107 DAP), provided significantly better control of disease (AUDPC) and longer FEP than did the single-spray and non-sprayed treatments. This improved disease control was also reflected in the higher grain yields achieved by these treatments.

Spray treatment 2, (beginning 93 DAP when disease was 2% on the basal five leaves), provided the lowest disease (AUDPC = 32) of the single-spray treatments and had the longest FEP (29 days), although this was not reflected in higher grain yields. Treatment 7, initiated 93 DAP when lesions were on the basal five leaves, also had the lowest disease (AUDPC = 9) and longest FEP (54 days), and among the highest grain yields, of the two-spray treat-

ments. The three-spray program provided control of disease (AUDPC) similar to that of treatment 7. Although the three-spray treatment provided the longest FEP, it was not significantly different from treatment 7. The three-spray treatment also produced the highest grain yield, but yield was not significantly higher than that with other, two-spray, treatments except treatment 8.

Only the multiple-spray treatments and treatment 5 reduced infection rates. The remaining single-spray treatments had infection rates similar to or higher than that of the nonsprayed treatment.

DISCUSSION

Farmers in KwaZulu-Natal receive approximately US\$139 ton⁻¹ for maize. Farmers who normally harvest 5 tons of grain ha⁻¹ can lose between 1 and 3 tons of grain ha⁻¹ from GLS. The cost of fungicide is US\$ 25 ha⁻¹ and the cost of aerial application is US\$11 ha⁻¹, making a total cost for control of US\$36 ha⁻¹. The break-even increase in grain yield is therefore 259 kg ha⁻¹. Responses to single-spray treatments varied between 875 and 2,705 kg ha⁻¹, to two sprays were between 1,310 and 4,334 kg ha⁻¹, and to three sprays were between 2,020 and 4,691 kg ha⁻¹. Cost of fungicide treatments was therefore economically justified.

Yield is a function of photosynthesis carried out by the plant and is related to the leaf area and its duration after flowering (5). The top eight or nine leaves contribute 75 to 90% to grainfill (1). Further, the number of kernels on the ear is established at anthesis (9). It is therefore important to maintain the upper leaves in a healthy condition until physiological maturity, if maximum yields are to be achieved. Foliar diseases such as GLS can, under favorable conditions, result in extensive leaf blighting, leading to loss in grain yield. The loss in photosynthetic area also causes depletion of carbohydrate from the stalk in an attempt by the plant to meet the demands of grain filling, and predisposes the plants to stalk-lodging, exacerbating the yield losses due to GLS (11).

In the 3 years of studies at CADI, GLS was observed in the crop well before anthesis. However, the disease was characteristically slow to develop and its main effect on yield loss was primarily a reduction in grainfill rather than in the number of kernels determined at anthesis. The trials consistently indicated that fungicide treatments were effective in delaying the leaf blighting process and those treatments with the longest FEP usually resulted in the highest grain yield.

Time and frequency of application of

Table 4. Gray leaf spot (GLS) disease development, effective periods of fungicide control, and grain yields, for fungicide treatments applied at different stages of disease development (1992 to 1993 season)

											Effective period				
Treat- ment no.	Fungicide application			At treat. date ^r	Disease severity (%) ^s					SAUD- PC ^t	<i>r</i> ^u	<i>R</i> ^{2v}	Length in days ^w	Period end (DAP)	Grain yield (kg/ha) ^x
	Dates applied	DAP ^p	Host stage ^q		Assessment (DAP)										
					83	96	112	117	145						
1	Unsprayed		Unsprayed ^y		3.4	7.8	21.4 a ^z	60.0 a	95.0 a	37 a	9.8 a	0.983			5,060
2	11 Jan.	67	Basal 1 to 2 leaves	0.8	1.0	1.0	3.4 c	11.1 b	47.5 bc	10 bc	5.6 b	0.967	29 a	96	5,830
3	27 Jan.	83	Basal 5 leaves	3.6	3.6	8.1	8.6 b	8.9 b	53.7 b	12 b	5.7 b	0.933	33 ab	116	6,550
4	10 Feb.	97	Up to ear height	5.0	4.8	5.0	5.6 bc	7.5 b	28.8 bc	9 b	3.9 b	0.904	26 a	123	6,190
5	11 Jan., 27 Jan.	67, 83	Basal 1 to 2 leaves	0.8, 1.1	1.1	1.3	1.8 c	3.2 b	30.6 bc	6 cd	4.3 b	0.932	41 b	108	6,370
6	11 Jan., 10 Feb.	67, 97	Basal 1 to 2 leaves	0.8, 1.3	1.1	1.3	1.4 c	2.7 b	29.4 bc	6 cd	4.3 b	0.905	49 c	116	5,870
7	27 Jan., 10 Feb.	83, 97	Basal 5 leaves	4.0, 4.5	4.3	4.4	5.6 bc	5.7 b	23.1 c	8 bcd	3.8 b	0.902	49 c	132	6,370
8	11 Jan., 27 Jan., 10 Feb.	67, 83, 97	Basal 1 to 2 leaves	0.8, 0.9, 1.0	0.8	0.9	1.1 c	1.9 b	18.8 c	4 d	3.8 b	0.915	52 c	119	7,080
SE (of a mean)							1.7	3.0	8.8	1.9	0.7		3.6		407.2
Grand mean							5.7	12.6	40.9	11.9	5.1		39.9		6,170
CV%							61.3	47.6	43.0	32.5	27.1		18.1		13.2

^p Days after planting.

^q For disease symptoms for first spray.

^r Disease severity estimated from logistic progress curves.

^s Disease severity is percent leaf tissue with symptoms of GLS.

^t Standardized area under disease progress curve.

^u Infection rate $\times$ 100, calculated by regressing the logistic transformation on time (DAP).

^v Coefficient of determination.

^w Calculated from logistic progress curves.

^x Average grain yield of fungicide-sprayed treatments was significantly higher than that of nonsprayed control ($P < 0.08$) according to Duncan's multiple range test.

^y Disease first observed 60 DAP, anthesis occurred 80 DAP, and physiological maturity at 149 DAP.

^z Means within a column having letters in common do not differ significantly ($P < 0.05$) according to Duncan's multiple range test.

fungicide treatments were critical to the length of the FEP. It is customary to begin a fungicide program as early as possible after detectable levels of disease develop. With the characteristically slow initial development of GLS disease, it is not easy to define the stage of "detectable level" of disease when spraying should commence.

Certainly the 1991 to 1992 studies indicated that spray applications beginning before GLS was observed were less effective, while applications made after the pathogen had begun to rapidly increase were also less effective in controlling the epidemic. These early experiments indicated that treatment should be initiated af-

ter the disease was observed but before high levels were present. Subsequent trials confirmed this conclusion.

Spray applications initiated when disease had progressed to the basal five leaves of maize usually provided the longest FEPs and highest grain yields of the single-spray treatments, but FEPs were of insufficient

Fig. 2. Logistic models of disease progress of gray leaf spot disease severity of fungicide treatments applied at different times of application against time for (A) 1991 to 1992, (B) 1992 to 1993, and (C) 1993 to 1994.

duration to protect the crop until it was physiologically mature. The multiple-spray treatments, with a longer combined FEP, delayed the development of disease longer, and resulted in better disease control and higher grain yields than single-spray treatments. Further, the number of basal leaves affected when the fungicide treatment was initiated played an important role in determining the length of control. This point is clearly shown in the 1993 to 1994 data, when two well-timed sprays, commencing when disease was 2% and present on the basal five leaves, provided control of disease as effective as the three-spray program commencing at lower disease ratings with disease present on the basal two leaves. The difference in yield between the two treatments was not significant ($P \leq 0.05$).

The importance of controlling disease through to physiological maturity was demonstrated. The relatively long period after breakdown in fungicide control until physiological maturity in the three-spray program in 1992 to 1993 resulted in a relatively small increase (29%) in grain yield. This long period after fungicide breakdown may explain the lack of significance be-

tween treatments in grain yield, in spite of significant differences in control of disease (AUDPC). In contrast, the three-spray treatment in 1993 to 1994 provided effective disease control until after physiological maturity and resulted in a 68% increase in grain yield. The object, therefore, of any spray program must be to delay disease in maize through to physiological maturity.

The trials determined that the optimum time to commence fungicide treatment is when the disease level is between 2 and 3% and lesions are visible on the basal five leaves of the plant. Further sprays may be necessary to provide control until the crop is physiologically mature. Spray intervals depend on duration of weather conditions favorable for disease, and results from the trials indicate that this interval may vary between 20 and 30 days. Yield responses to fungicide treatments appear to be a function of the growth stage when sprays are initiated, the amount of disease at spray date, the FEP, and control through to physiological maturity.

Experiments were conducted with the GLS-susceptible hybrid RS 5206. Resistance appears to be of a rate-reducing type, and less susceptible hybrids may react dif-

ferently to the timing and number of spray applications. Finally, the trials were conducted with equipment that provided full-cover spray application up to 450 liters ha^{-1} . Such medium-volume applications may not be feasible in commercial agriculture and more research is required on different methods of application and spray volumes, including low-volume aerial application.

ACKNOWLEDGMENTS

We thank Margie Whitwell for statistical assistance, and Pat Caldwell and Andy Cairns for editing the manuscript.

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Table 5. Gray leaf spot (GLS) disease development, effective periods of fungicide control, and grain yields, for fungicide treatments applied at different stages of disease development (1993 to 1994 season)

Treat- ment no.	Fungicide application			At treat. date ^s	Disease severity (%) ^t								SAU- DPC ^u	<i>r</i> ^v	<i>R</i> ^{2w}	Effective period		Grain yield (kg/ha)
	Dates applied	DAP ^q	Host stage ^r		Assessment (DAP)											Length in days ^x	Period end (DAP)	
					111	120	129	139	147	156	164							
1			Non- sprayed	...	14.1	20.0	71.3	85.0	87.5 a ^y	96.0 a	99.0 a	69 a	12.1 b	0.98	...	...	2,266 a*	
2	22 Jan.	88	Basal 2 leaves ^z	1.5	2.1	5.6	53.8	77.5	78.8 b	97.2 b	99.0 a	60 a	16.0 a	0.98	22 fg	110	3,141 ab	
3	27 Jan.	93	Basal 5 leaves	2.0	2.8	3.0	8.1	24.4	40.0 c	78.7 c	93.7 ab	32 cd	12.5 b	0.98	29 ef	122	4,211 bc	
4	10 Feb.	107	Up to ear height	10.0	7.5	7.5	17.5	29.4	39.4 c	87.5 c	95.2 ab	38 b	11.0 b	0.95	18 gh	125	4,033 bc	
5	16 Feb.	113	Above ear height	14.0	11.3	11.3	24.4	25.0	33.8 c	75.0 c	82.5 b	35 bc	7.4 cd	0.94	13 h	126	4,971 c	
6	22 Jan., 16 Feb.	88, 113	Basal 2 leaves	1.5, 3.1	2.8	3.8	12.5	13.8	14.4 d	31.9 d	63.7 c	17 e	7.3 cd	0.96	36 de	124	6,525 d	
7	27 Jan., 16 Feb.	93, 113	Basal 5 leaves	2.0, 2.0	2.1	2.1	3.9	5.0	5.0 e	14.4 e	50.0 d	9 f	6.5 d	0.89	54 b	147	6,600 d	
8	10 Feb., 3 Mar.	107, 128	Up to ear height	10.0, 20.0	8.8	8.8	22.5	30.6	37.5 c	77.5 c	86.2 ab	37 bc	8.4 c	0.97	38 cd	145	4,389 bc	
9	16 Feb., 9 Mar.	113, 134	Above ear height	14.0, 26.0	12.5	13.8	26.3	28.8	32.5 c	46.9 c	58.7 cd	30 d	4.4 e	0.98	44 c	157	6,235 d	
10	22 Jan., 16 Feb., 9 Mar.	88, 113, 134	Basal 2 leaves	1.5, 3.0, 9.0	4.3	5.5	8.8	10.0	10.6 de	18.1 de	33.7 e	12 f	4.1 e	0.95	68 a	156	6,957 d	
SE (of a mean)									2.9	4.6	4.5	1.5	0.5		2.6		814.8	
Grand mean									37.9	62.3	76.4	34	9.0		36.0		4933	
CV%									15.5	14.7	11.7	9.1	11.9		14.3		16.5	

^q Days after planting.

^r For disease symptoms for first spray.

^s Disease severity estimated from logistic progress curves.

^t Disease severity is percent leaf tissue with symptoms of GLS.

^u Standardized area under disease progress curve.

^v Infection rate $\times 100$, calculated by regressing the logistic transformation on time (DAP).

^w Coefficient of determination.

^x Calculated from logistic progress curves.

^y Mean within a column having letters in common do not differ statistically ($P \leq 0.05$) according to Duncan's multiple range test.

^z Disease first observed 53 DAP, anthesis occurred 78 DAP, and physiological maturity at 153 DAP.

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