Utilization of a Multispectral Radiometer to Evaluate Fungicide Efficacy to Control Late Leaf Spot in Peanut

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ABSTRACT

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Reflectance measurements were compared to visual assessment methods in 1985, 1986, and 1987 in Plains, GA, to measure fungicide efficacy for the control of late leaf spot caused by *Cercosporidium personatum*. Percent reflectance of 800-nm wavelength radiation was recorded from peanut canopies treated with different test fungicides by using a hand-held multispectral radiometer. In all but one case, percent reflectance increased in a linear fashion as visual disease assessments decreased. Analysis of variance and mean separation tests for visual versus remotely sensed assessments revealed that percent reflectance-based measurements had lower coefficients of variation than visually based assessment schemes. Higher coefficients of determination (R^2) and lower standard errors of Y (pod yield) were obtained when percent reflectance values were regressed against Y compared to the R^2 values and standard errors obtained from regression equations employing visual assessments as the independent variable. Reflectance-based measurements were also faster and easier to obtain than visually based assessment methods. Percent reflectance values explained more of the variation in visual leaf spot assessments using a 1-10 rating scale compared to visual estimates of percent disease severity. Rank correlations for the ranking of fungicide treatments (based on the different assessment methods) with the rankings for pod yield revealed that reflectance-based assessments had a higher rank correlation with pod yield rankings than did visual assessment methods. Measurements of reflected radiation at 800 nm from peanut canopies can provide rapid, objective, and precise measurements to evaluate fungicide efficacy to control late leaf spot in peanuts.

Additional keywords: disease assessment, disease control, remote sensing.

Numerous disease assessment methods have been developed to evaluate the efficacy of fungicides to control foliar diseases of peanut (*Arachis hypogaea* L.) (23). Disease assessment systems used to measure fungicide efficacy to control late leaf spot, caused by *Cercosporidium personatum* (Berk. and Curt.) Deighton, have been based on: incidence of infected leaves or leaflets (13,16), percent defoliation of leaves or leaflets (4,16,19), estimates of percent disease severity (or disease proportion) made with or without the aid of standard area diagrams (11), indices that integrate defoliation and disease severity estimates (19), and subjective rating scales (5,7,8,24). However, several researchers have noted problems associated with the visual evaluation of disease intensity (18,21) and/or the statistical treatment of visually based data (10,12,22). Remote sensing technology may provide an alternative to visually based assessment methods.

Great progress has been made in the last 10 yr in the development of remote sensing data acquisition systems (15). Multispectral radiometers have been used to quantify differences in stand densities of winter wheat (1,3) and as a tool to monitor cereal rust development (20). Nutter (15) showed that a hand-held multispectral radiometer operated at the 800 ± 13-nm wavelength band range could detect defoliation gradients caused by late leaf spot and proposed that measurements of percent reflectance could be used as a method to evaluate the efficacy of disease control tactics such as the use of fungicides. The objectives of this study were to 1) determine whether a multispectral radiometer could provide fast and precise measurements to evaluate the efficacy of fungicides for control of late leaf spot, 2) compare the ranking of mean treatment effects using a multispectral radiometer with the ranking of means for assessment systems used by Littrell (11) and Brenneman (5), and 3) determine the relationship of each assessment system with yield. A preliminary report has been published (17).

MATERIALS AND METHODS

Fungicide concentration study, 1985. To differentially reduce the apparent infection rate of late leaf spot and obtain a range of late leaf spot disease intensity levels, peanut plots (cv. Florunner) six rows wide (97 cm apart) and 8.3 m long were treated with either 2×, 1×, 0.5×, 0.25×, 0.13×, or 0× concentrations of Bravo 500F (chlorothalonil), where 1× concentration = 1.3 kg/ha a.i. The experimental design was a randomized complete block with four replications. Fungicide applications began on 24 July when disease incidence was estimated to be 1 ± 0.5% in all plots. This time was determined by randomly sampling 10 branch stems from each plot, counting the number of infected leaflets (1 or more leaf spot lesions) and dividing this by the total number of leaflets in the sample. Subsequent chlorothalonil applications were made at 8-10 day intervals on 3 August, 13 August, 22 August, and 30 August.

Ten central main stems were randomly sampled from each plot by excising the stems at ground level on 22 September 1985. Central stems were then assessed for percent disease severity by first determining percent defoliation of leaflets and then determining the percent necrotic area occupied by *C. personatum* lesions for the leaflets remaining on each stem sample. These two measurements were integrated by modifying the equation for total disease severity published by Plaut and Berger (19):

$$X_t = [100 - D)\ X_v] + D,$$

where X_t represents total percent disease severity due to late leaf spot, X_v is the percentage of necrotic leaf area occupied by lesions, and D is the percentage of leaflets defoliated. The mean percent disease severity for each plot was obtained by averaging the disease severity estimates for the 10 stems from each plot.

The amount of green leaf area in grams remaining on central stems was indirectly estimated by removing the primary leaf at each node (if not defoliated), placing these in a paper bag, and drying the leaf samples overnight in a forced-air oven at 50 C. The samples were then weighed and the dry weight (g) recorded. Earlier work showed a high correlation ($r = 0.96$) between leaf area index and the dry weight (g) of leaves from branch stem samples (16).

Radiometric assessments. Percent reflectance of sunlight reflected from peanut canopies was recorded in the 800 ± 13 nm range using a multispectral radiometer (CROPSCAN, Inc., Fargo, ND) on 22 September. A data acquisition system consisting of an analog to digital converter interfaced with a Radio Shack model 100 computer (Tandy Corp., Fort Worth, TX) was used to acquire and store voltage values from which percent reflectance values were calculated. Reflectance values were recorded from the two center rows of each plot just before the time central stems were sampled. This was accomplished by placing the base of the radiometer sensor support pole approximately 0.5 m into the plot and leaning the support pole of the radiometer sensor over the center of the row. A bubble spirit level mounted on the support pole was used to level the radiometer sensor that was positioned approximately 2 m above the peanut canopy. At this height the radiometer recorded percent reflectance from an area of the canopy the diameter of which was one-half the height of the distance from the sensor to the crop canopy (i.e., an area approximately 1 m in diameter). Reflectance measurements were recorded during cloud-free periods between 1200 and 1400 hours EST.

Fungicide efficacy trials. Fungicide efficacy experiments for the control of late leaf spot were conducted at the Southwest Branch Experiment Station in Plains, GA, during the years 1986 and 1987. The susceptible cultivar Florunner was used in each experiment. Methods used in 1986 were the same as those used in a 1985 report (11) except that peanuts were planted on 28 April and inverted on 13 October.

Late leaf spot assessments. In 1986, disease evaluations were made on 11 September and 7 October by collecting three central stems from each plot and determining the percent necrotic tissue (disease severity) on each leaflet at the sixth node below the first fully expanded leaf. This was accomplished by comparing infected leaves to standard area diagrams depicting percent necrotic tissue ranging from 0.1 to 20% (11). Percent reflectance of sunlight in the 800 ± 0.13 nm wavelength range was also measured from each plot on the same date just before the time that central stems were sampled for visual evaluation of percent necrosis.

Methods used for the visual evaluation of fungicide efficacy in the 1987 experiment have been previously published (5). In this study, disease evaluations were made on 25 August and 9 September with a subjective 1–10 rating scale published by Chiteka et al (7), where 1 = no disease and 10 = dead plants. Radiometric assessments were made as described earlier in this study within 24 hr of time when visual ratings were obtained.

Data analysis. Data were subjected to ANOVA, and mean separations were performed using the Waller-Duncan *K*-ratio test ($P = 0.05$). Coefficients of variation were calculated for each assessment method used in each experiment to compare the degree of precision with which treatment effects were measured (9). Linear regressions were performed to measure the amount of variation in yield that was explained by the different methods of leaf spot assessment and to measure the strength of the relationships between visual and remote sensing methods (24). Rank correlations were performed on the data obtained from the 1986 and 1987 fungicide efficacy trials to measure the agreement among assessment methods in the ranking of treatments for fungicide efficacy with the ranking of treatments for pod yield. The time required for sampling and obtaining data for each assessment method was also recorded.

TABLE 1. Effect of fungicide concentration on percent reflectance, percent disease severity, dry weight[a] and pod yield of Florunner peanut in 1985

Fungicide concentration[b]	Disease severity (%)	Dry weight (g)	Percent reflectance (800 nm)	Yield (kg/ha)
2×	25.1	18.6	46.5	3,337
1×	33.0	17.0	45.2	3,285
0.5×	37.4	15.4	42.3	2,727
0.25×	44.8	13.8	40.8	2,304
0.13×	61.9	10.7	37.7	2,110
0	70.3	3.0	31.3	1,356
LSD	10.09	3.93	2.77	296.2

[a] Dry weight of leaves remaining on 10 central stem samples per plot.
[b] Bravo 500F (chlorothalonil), where 1× concentration = 1.3 kg/ha a.i.

RESULTS

Fungicide concentration experiment. Peanut disease severity increased and percent reflectance and dry weight of leaves from central stem samples decreased as chlorothalonil active ingredient concentrations were reduced (Table 1). Radiometric assessments explained more of the variation in pod yield and had a lower standard error of the estimate and coefficient of variation (CV) than either percent disease severity or dry weight measurements (Table 2).

Fungicide efficacy experiment, 1986. Percent reflectance values obtained on 3 August from the 1986 fungicide efficacy experiment were not significantly different from each other (Fig. 1A), and late leaf spot lesions were not found in the experimental area on this date. By 11 September, percent reflectance at 800 nm was significantly lower in several treatments including the nonsprayed control (trt 30) (Fig. 1B). Lower percent reflectance values on this date were associated with higher visual estimates of percent disease severity (Table 3).

Percent reflectance in the nonsprayed control was reduced by more than half by 21 September (Fig. 1C), and by 7 October, percent reflectance in the nontreated controls averaged only 13.6% compared with 35.8% in treatment 16 (chlorothalonil, 1.3 kg/ha [Bravo 720]) and treatment 26 (tebuconazole, 0.21 kg/ha [HWG 1608]) (Fig. 1D). Again, treatments with lower percent reflectance values were associated with higher visual ratings for late leaf spot severity (Table 3). Coefficients of variation were 4–10 times higher on both 11 September and 7 October when the visual method was used to measure fungicide efficacy compared with the percent reflectance method.

Fungicide efficacy experiment, 1987. In the 1987 experiment, late leaf spot lesions could not be found in the experimental area on 14 July, and no significant differences were found in percent reflectance values among treatments on that date (Fig. 2A). By 25 August, late leaf spot epidemics were well under way, and significant differences in both percent reflectance and visual disease ratings were obtained (Fig. 2B, Table 4). Percent reflectance was lowest and visual disease ratings highest in the nontreated control (treatment 17), whereas percent reflectance was significantly higher in all other treatments on this date (Table

TABLE 2. Estimated regression parameters for percent disease severity, dry weight of leaflets, and percent reflectance (800 nm) with pod yield of Florunner peanut from plots treated with different active ingredient concentrations of chlorothalonil in 1985

Independent variable	Intercept	Slope	r^2	Standard error of the estimate	Coefficient of variation	Person-hours required (hr, min)
Disease severity	4,273	−38.86	82.0	385.4	19.78	11 hr, 45 min
Dry weight	1,042	116.79	77.5	451.9	20.53	7 hr, 30 min
Reflectance	−860	101.69	87.1	327.2	5.98	0.hr, 16 min

4). By 9 September, late leaf spot had become severe, and percent reflectance values ranged from 24.2% (nonsprayed control) to 57.3% (SDS 66534, treatment 16) (Fig. 2C). SDS 66534, chlorothalonil (Bravo 720) (treatment 1), and spotless 25 wp + Agridex (treatment 15) had the highest reflectance values, and these three treatments were also found to have the three lowest disease ratings (Table 4). Coefficients of variation were slightly lower for the radiometric method compared with the rating scale method on both assessment dates (Table 4).

Relationship of assessment methods with pod yield. Based on the slopes of the linear regression equations, pod yield increased as reflectance in the 800-nm wavelength range increased, whereas pod yield decreased as visual assessment values increased (Table 5). Although all assessment methods resulted in regression models in which the *F*-statistic was significant, that is, a linear relationship was found between assessments and yield, radiometric assessments explained more of the variation in yield (R^2) than either of the two visual methods.

Rank correlations were obtained for each assessment method and date to determine how well the ranking of treatments for each assessment method correlated with the ranking of treatments for pod yield (Table 5). Reflectance values for fungicide treatments had a higher rank correlation with pod yield than either of the other two visual assessment methods.

Relationship between percent reflectance and visual assessment methods. A linear relationship was found between percent reflectance and percent disease severity for both assessment dates. In the 1986 experiment on 11 September, percent disease severity ranged from 0.1 to 3.7%, whereas percent reflectance values ranged from 31.5 to 52% (Fig. 3). Percent disease severity decreased by 0.15 and 0.47% for each 1% increase in percent reflectance on 11 September and 7 October, respectively. Percent reflectance values explained 82.1 and 74.2% of the variation in percent disease severity on 11 September and on 7 October, respectively.

In 1987, a quadratic relationship was found between percent reflectance measurements and visual disease ratings on 25 August (Fig. 4). Percent reflectance values explained 95.6% of the variation in visual disease rating using the quadratic model and 90.7% using the linear model. On 8 September, the relationship was linear, and visual disease rating decreased by 0.11 for each 1% increase in percent reflectance. Reflectance values explained 95.8% of the variation in visual disease rating on this date.

DISCUSSION

Calpouzos (6) stated that disease assessment systems should be fast, accurate, and reliable. Shokes et al (23) further suggested that an assessment system should be easy to use so that those unfamiliar with the method may be rapidly trained and that the assessment method should be applicable over a wide range of conditions. Assessment systems should also provide evaluations that have a good relationship to yield (13). Reflectance measurements were faster and easier to obtain, had a better relationship to yield and had lower coefficients of variation and standard errors compared with the visual assessment methods currently employed.

Since the peanut plant produces pods underground, it is possible that soilborne factors reducing pod yields (i.e., nematodes, pod rot, etc.) could actually result in increased green leaf area due to a decreased demand on the plant for photosynthate by develop-

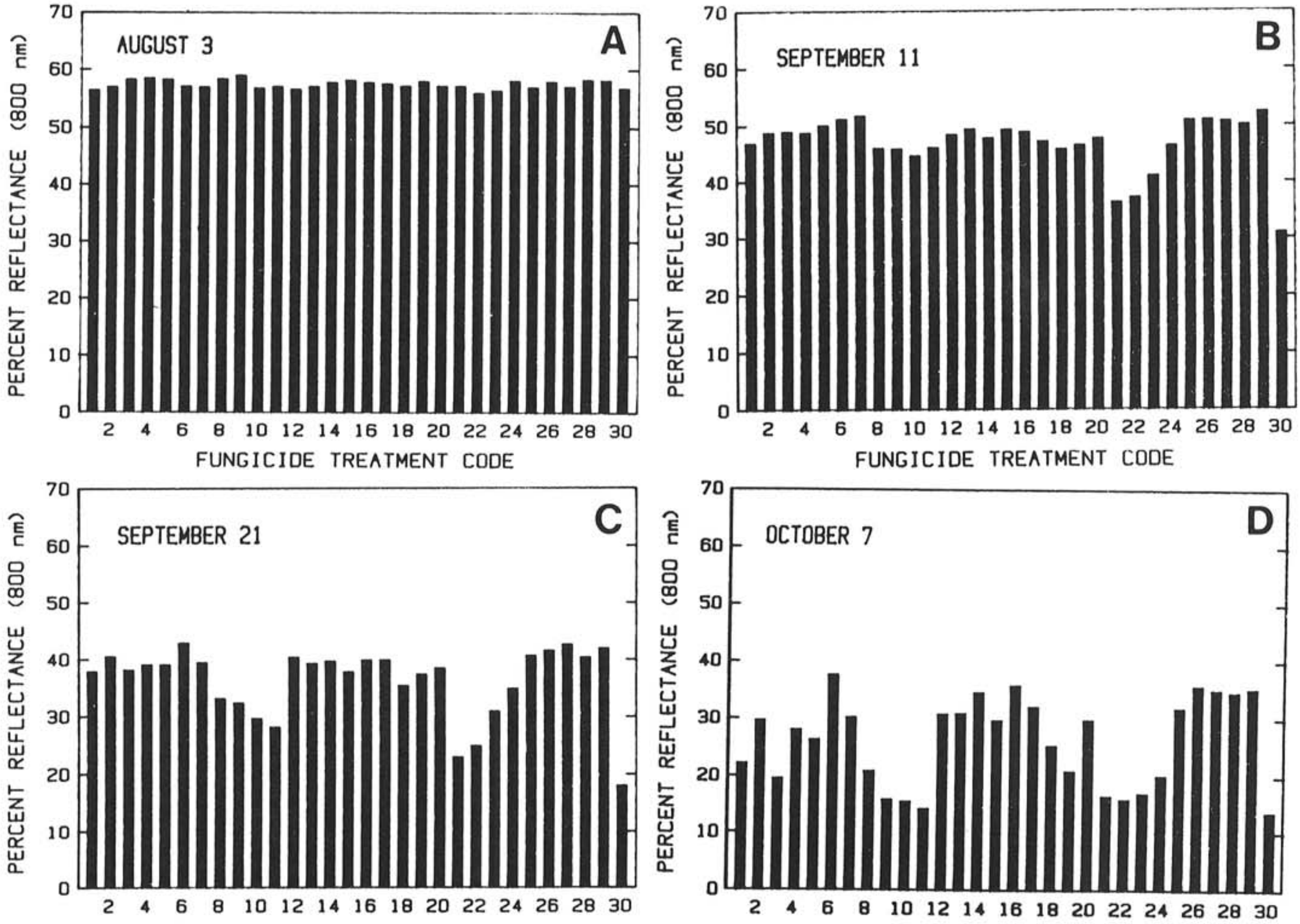

Fig. 1. Percent reflectance of sunlight (800 nm) from peanut canopies treated with different fungicides to control late leaf spot on four dates in 1986. The fungicide code corresponds to the treatment numbers used in Table 3.

TABLE 3. Evaluation of fungicide efficacy to control late leaf spot based on visual ratings for disease severity, percent reflectance, and pod yield obtained from peanut plots treated with different fungicides in Plains, GA, in 1986

	September 11		October 7		
Treatment dose/ha	Visual	Reflectance %	Visual	Reflectance %	Yield (kg/ha)
1. SAN 619 F, 61.8 g a.i.	0.6 e–i	46.9 d-g[a]	14.1 b-i	22.2 e-h	4,517 f-g
2. SAN 619 F, 86.5 g a.i.[b]	0.8 e–i	48.8 a-f	9.4 h-m	29.6 b-d	5,326 a-e
3. SAN 724 F, 61.8 g a.i.	0.5 f-i	49.0 a-e	17.1 a-d	19.5 g-k	5,336 a-e
4. SAN 724 F, 86.5 g a.i.	0.5 f-i	48.8 a-f	15.1 a-g	28.0 c-e	5,305 a-e
5. XE779 25W, 89.6 g a.i., + 0.5% crop oil	0.66 e-i	50.1 a-e	12.6 d-k	26.3 c-f	5,726 ab
6. XE799 25W, 134.4 g a.i., + 0.5% crop oil	0.5 f-i	51.2 a-c	8.9 i-m	37.6 a	5,777 a
7. XE779 EC, 89.6 g a.i., + 0.5% crop oil	0.4 f-i	51.8 ab	7.8 j-m	30.2 b-d	5,479 a-e
8. XE779 EC, 134.4 g a.i./ Bravo 720, 1.3 kg a.i.[c]	1.8 c-d	46.0 fg	18.8 a-c	20.9 f-i	5,286 a-f
9. RO 15-1297 4E 140.0 g a.i.	0.5 f-i	45.9 fg	14.6 a-h	15.8 i-k	4,773 e-g
10. RO 15-1297 4E 105.0 g a.i.	1.1 d-h	44.6 g	19.1 ab	15.4 i-k	4,462 gh
11. RO 15-1297 4E 70.0 g a.i.	1.2 d-f	46.1 fg	19.5 ab	14.1 jk	4,920 c-g
12. RO 15-1297 4E 105.0 g a.i. +Dithane M-45 1.7 kg	0.3 h-i	48.4 b-g	11.2 e-h	30.8 b-d	4,837 e-h
13. Bravo 500 a 1.3 kg a.i.	0.6 e-i	49.4 a-f	14.0 b-i	30.9 b-d	4,718 e-h
14. Bravo 500 b 2.125 pts 1.3 kg a.i.	0.2 i	47.8 b-g	8.9 i-m	34.6 ab	4,966 b-g
15. Bravo 500 c 2.125 pts 1.3 kg a.i.	0.5 f-i	49.3 a-f	14.7 a-h	29.7 b-d	4,352 g-i
16. Bravo 720 a 21.5 pts 1.3 kg a.i.	0.3 hi	48.9 a-f	10.5 f-m	35.8 ab	4,383 gh
17. Bravo 720 b 1.5 pts 1.3 kg a.i.	0.4 f-i	47.2 c-g	11.1 e-h	32.1 a-c	4,856 e-h
18. SDS 64220 dg 3.4 kg	0.9 e-i	45.8 fg	16.1 a-f	25.3 d-g	4,810 e-h
19. SDS 64220 gg 3.4 kg	0.6 e-i	46.5 e-g	13.1 c-j	20.9 f-i	4,489 gh
20. Bravo 720 1.3 kg a.i. + Super Six 2.34 L	1.2 d-f	47.7 c-g	10.0 g-m	29.8 b-d	4,896 d-h
21. GTA 2.3 L	3.0 ab	36.3 i	16.9 a-d	16.5 h-k	3,463 i
22. GTA 2.9 L	2.4 bc	37.2 i	18.5 a-c	15.9 i-k	3,591 ij
23. GTA 3.5 L	1.8 cd	41.0 h	16.4 a-e	17.0 h-k	3,399 i
24. Bravo 720 0.6 kg a.i.	1.4 de	46.4 e-g	17.9 a-d	20.2 f-j	4,727 e-h
25. HWG 1608 189 g a.i.	0.8 e-i	50.9 a-d	7.9 j-m	31.9 a-c	5,479 a-e
26. HWG 1608 210 g a.i.	0.6 e-i	51.0 a-c	6.8 lm	35.8 ab	5,790 a
27. HWG 1608 210 g a.i.[b]	0.5 f-i	50.7 a-d	12.7 d-k	35.1 ab	6,001 a
28. HWG 1608 252 g a.i.	0.7 e-i	50.1 a-e	5.2 m	34.7 ab	5,680 a-c
29. HWG 1608 252 g a.i.[b]	0.6 e-i	52.4 a	7.4 k-m	35.3 ab	5,634 a-d
30. Control	3.7 a	31.0 j	19.90 a	13.6 k	4,132 h-i
Coefficient of variation	51.0	5.0	34.6	8.41	11.58

[a]Means with the same letter in the same column are not significantly different according to the Waller-Duncan k-ratio test ($P \leq 0.5$).
[b]Indicates 21 day schedule. All other treatments were applied at 14-day intervals.
[c]Alternated fungicides.

TABLE 4. Evaluation of fungicide efficacy to control late leaf spot based on a leaf spot disease rating scale, percent reflectance, and pod yield obtained from peanut plots treated with different fungicides in Plains, GA, in 1987

		August 25		September 9		
Treatment	Dose	Visual leaf spot[b] rating	Percent reflectance	Visual leaf spot rating	Percent reflectance	Yield (kg/ha)
1. Chlorothalonil	1.3 kg a.i.	2.2 j[c]	64.0 a	3.5 g	57.2 a	4,154
2. RH-7592 2F + Agridex	0.13 kg a.i. + 1% v/v	4.9 g	59.7 a	5.8 de	45.0 b	3,897
3. RH-7592 2F + Agridex	0.28 kg a.i. + 1% v/v	4.0 h	59.9 a	5.4 e	48.3 b	4,283
4. C 2338 10% EC	0.14 kg a.i.	6.8 b-e	43.4 b-e	7.6 ab	27.2 ef	2,494
5. C 2338 10% EC	0.28 kg a.i.	7.0 b–d	44.6 b-d	7.6 ab	26.3 ef	2,687
6. C 2338 10% EC	0.42 kg a.i.	6.6 c-f	43.2 c-e	6.9 c	27.9 ef	2,439
7. LS 84-608 AQ 100F + Penetrator 3	0.17 kg a.i. 0.29 L	6.2 f	49.0 b	7.1 bc	30.9 de	3,237
8. LS 84-608 AQ 100F	0.17 kg a.i.	6.8 b-e	42.9 c-e	7.7 a	25.0 ef	2,760
9. LS 84-608 250F, oil + Penetrator 3	0.17 kg a.i. 0.29 L	6.3 e-f	47.4 bc	6.9 c	34.2 c	2,880
10. LS 84-608 250F, oil	0.17 kg a.i.	6.4 d-f	47.4 bc	6.9 c	28.5 d-f	2,696
11. FBC 39865 25wp	0.14 kg a.i.	4.7 g	58.6 a	6.2 d	38.4 c	3,944
12. FBC 29865 25wp	0.28 kg a.i.	3.7 hi	59.5 a	5.6 de	45.4 b	4,704
13. Spotless 4.4% G	0.62 kg a.i.	7.4 ab	38.2 e	7.7 ab	27.9 ef	2,265
14. Spotless 4.4% G	0.99 kg a.i.	7.2 a-c	39.8 de	7.2 a-c	30.1 d-f	2,393
15. Spotless 25wp + Agridex	0.14 kg a.i. 1% v/v	3.3 i	63.8 a	4.4 f	55.2 a	5,512
16. SDS 66534	2.3 L	2.3 j	63.7 a	4.1 f	57.3 a	4,640
17. Nonsprayed check		7.6 a	32.8 f	7.6 ab	24.2 f	1,898
Coefficient of variation		7.20	6.95	6.22	6.15	14.64

[a]All treatments were applied on a 14-day schedule for a total of seven applications except for the Spotless granular formulations in which a single application was made 22 days after planting.
[b]Visual rating for late leaf spot based on a subjective 1–10 rating scale where 1 = no disease and 10 = dead plants (7).
[c]Means with the same letter in the same column are not significantly different according to the Waller-Duncan K-ratio test (≤ 0.05).

ing pods. However, such an effect was not observed in these studies. Also, fungicide efficacy experiments are normally conducted in such a manner as to eliminate the potential adverse effects of other crop-limiting pests (weeds, insects, other pathogens). This ensures an accurate and precise measurement of the fungicidal effects of a compound or mixture of compounds on a relatively few diseases (5,11,23). Shokes et al (23) have outlined procedures to evaluate fungicides for the control of foliar diseases of peanuts. We found that, in addition to the leaf spot assessment methods they outlined, the efficacy of fungicides to control foliar diseases (such as late leaf spot) can also be determined by recording the amount of sunlight reflected from peanut canopies in the 800-nm wavelength range. This is because a good relationship exists between healthy leaf area and percent reflectance (1,3,14). As late leaf spot caused more spotting and defoliation (thereby reducing healthy leaf area), percent reflectance at 800 nm decreased in a linear fashion. Conversely, the more efficacious a fungicide is in protecting and maintaining healthy leaf area, the higher the percentage of light (radiation) in the 800-nm wavelength range that will be reflected.

Fungicide tests are often conducted with the goal of determining how candidate fungicides rank in terms of disease control, and yield and recognized industry standards are included in experiments for this purpose. Whereas cardinal numbers are generally used to indicate the magnitude of disease intensity in discrete units, maximum disease intensity levels often vary from location to location and/or from year to year. The relative ranking of treatments in fungicide efficacy experiments is of particular importance to those in industry who must determine whether or not registration for a specific host and pathogen should be pursued (23). Ordinal numbers indicate the relative position of a treatment in a fungicide efficacy experiment, but the method of assessment to measure the magnitude of efficacy must have sufficient resolution to be able to differentiate and rank treatment

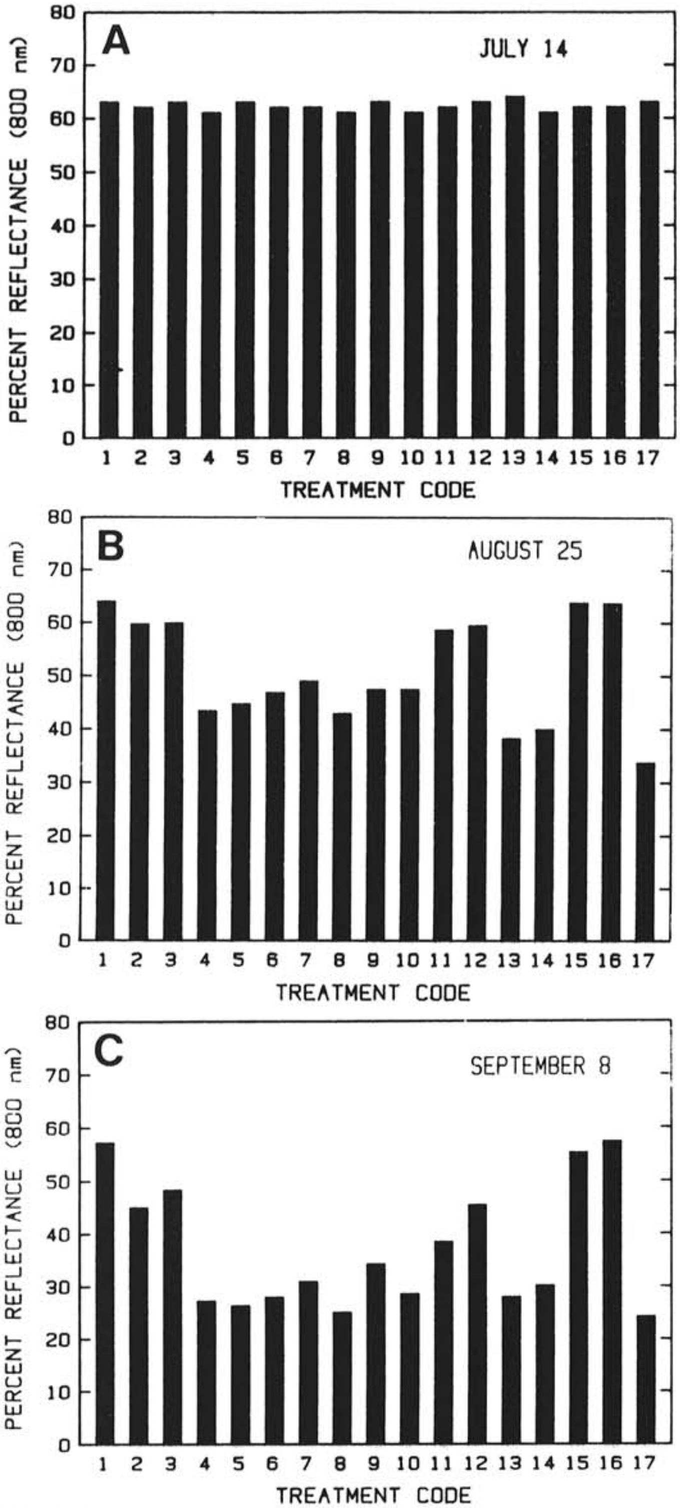

Fig. 2. Percent reflectance of sunlight (800 nm) from peanut canopies treated with different fungicides to control late leaf spot on three dates in 1987. The fungicide code corresponds to the treatment numbers used in Table 4.

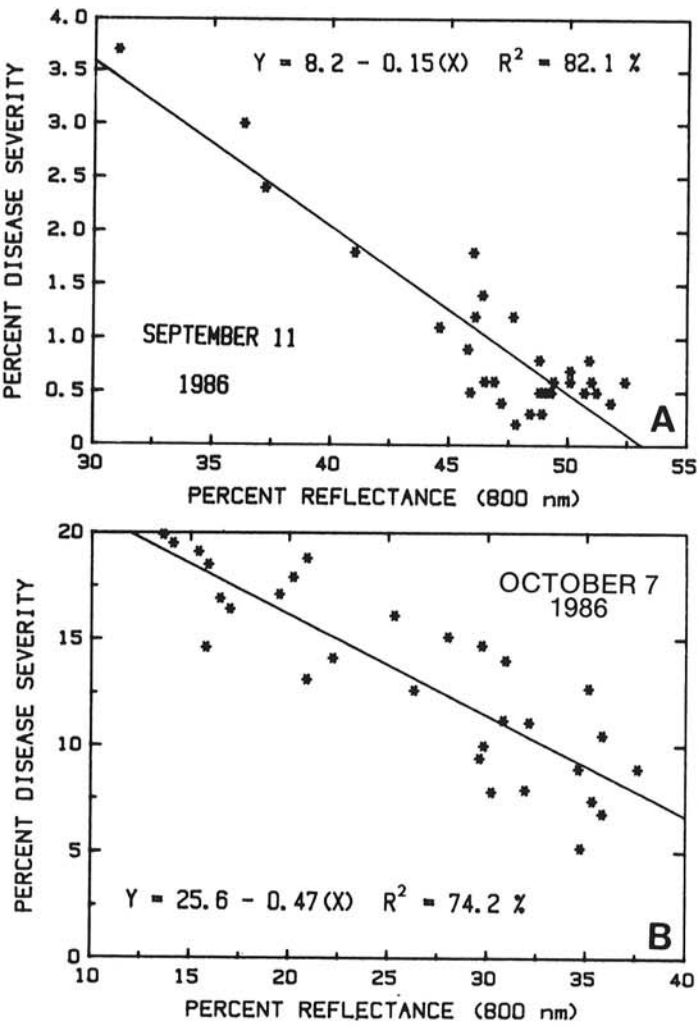

Fig. 3. Relationship between visual estimates of percent disease caused by late leaf spot and percent reflectance of sunlight recorded on 11 September (A) and 7 October (B), from peanut canopies treated with different fungicides in 1986 at Plains, GA. Data points are the means of four replications.

TABLE 5. Estimated regression parameters and rank correlations for yield (Y) versus leaf spot assessment methods (X) in fungicide efficacy experiments conducted in 1986 and 1987

Year-Date	Dependent variable	Independent variable	Intercept	Slope	Standard error of Y	Coefficients of determination	Rank correlation
1986							
Sept. 11	Yield	Disease severity[a]	5,385.6	−498.5	562.2	35.6	0.32
Sept. 11	Yield	Reflectance[b]	−353.4	112.1	433.8	61.7	0.76
Oct. 7	Yield	Disease severity	6,146.8	−94.1	568.3	34.2	0.55
Oct. 7	Yield	Reflectance	3,435.6	56.1	502.4	45.9	0.59
1987							
Aug. 25	Yield	Disease rating[c]	6,357.7	−546.2	413.2	85.9	0.64
Aug. 25	Yield	Reflectance	−1,663.2	99.5	344.2	90.2	0.93
Sept. 9	Yield	Disease rating	7,734.2	−687.6	532.7	76.5	0.86
Sept. 9	Yield	Reflectance	311.5	82.3	428.8	84.7	0.88

[a]Disease severity was assessed by determining the percent necrotic tissue on each leaflet at the sixth node below the first fully expanded leaf on three central stems/plot.
[b]Percent reflectance of sunlight from each plot canopy was measured using a CROPSCAN radiometer.
[c]Disease ratings were obtained using a 1–10 visual rating scale (7).

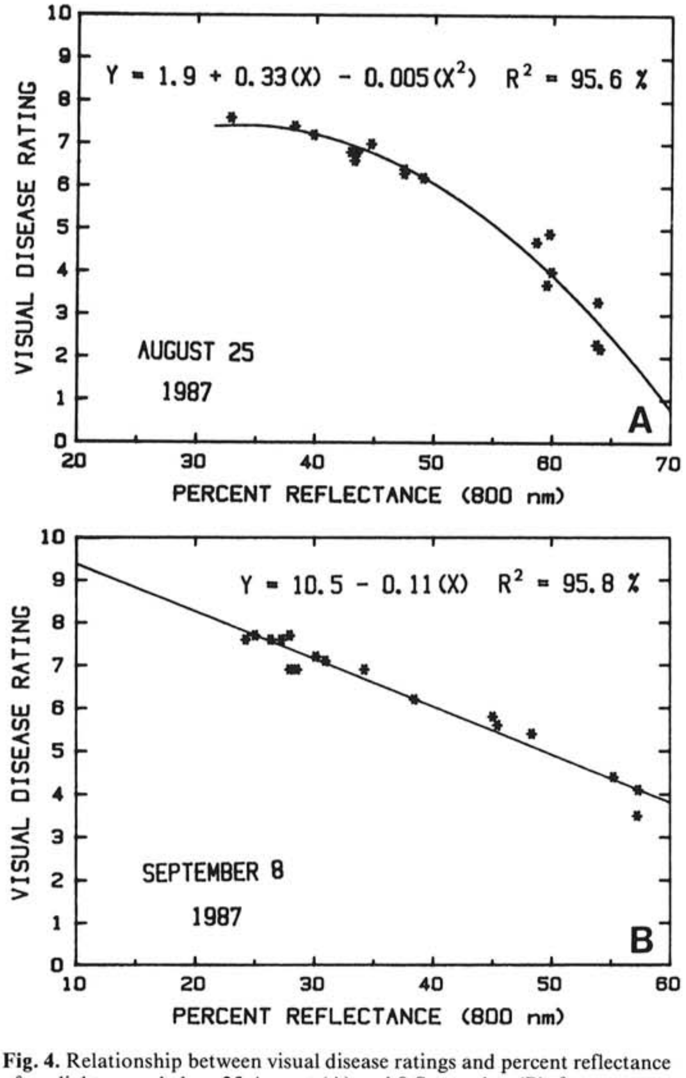

Fig. 4. Relationship between visual disease ratings and percent reflectance of sunlight recorded on 25 August (A) and 8 September (B), from peanut canopies treated with different fungicides in 1987 at Plains, GA. Data points are the means of four replications.

effects accordingly. A disadvantage of most rating scales is that they are limited in the number of values that can be assigned (e.g., 1–10) unless the assessor can accurately and precisely interpolate between rating values. Numerical rating scales (7,25) do not offer the broad and continuous range of possible scores afforded by remote sensing; therefore, they may lack the resolution to determine whether one fungicide is actually equal to or better than the recognized industry standard. Reflectance measurements may provide a more precise alternative to visual assessment methods in assigning values of magnitude to assess fungicide efficacy since remote sensing of fungicide-treated plots offers an objective means to obtain quantitative data over a continuous and broad range of reflectance values (20–60% in the 9 September 1987 data).

Determining the coefficient of variation for each assessment method provided an index to compare rating methods for their resolution in discriminating disease levels. CVs were lower for reflectance-based measurements compared with visually based estimates of leaf spot intensity. There are two main possibilities as to why CVs were lower for reflectance-based measurements. First, there is often a high degree of inter- and intrarater variability associated with the use of visual rating scales (12,22) and visually obtained disease intensity measurements (18,21). This error is greatly reduced within and among raters when a radiometer is used. Adcock et al (2) have shown that there was a negligible error term among raters when a multispectral radiometer was used to assess herbicide injury to soybeans compared with the error term for visually based evaluations. Second, the radiometer integrates readings over a large area (1 m in diameter) and therefore more peanut stems are included in each assessment, compared with the three- and five-stem sampling methods. Although increasing sample size for visual assessment systems would probably lower CVs, the cost of labor to sample and evaluate additional stems would also increase and the inter- and intrarater variability would still be present.

The results of this study show that measurements of reflected radiation in the 800-nm wavelength range can be used to obtain fast, accurate, and precise information to evaluate fungicide efficacy in peanuts. This technique should be useful as a means to evaluate other disease control tactics in peanut or as a means to evaluate fungicide efficacy in other field or row crops.

LITERATURE CITED

1. Aase, J. K., and Siddoway, F. H. 1980. Determining winter wheat stand densities using spectral reflectance measurements. Agron. J. 72:149-152.
2. Adcock, T. E., Nutter, F. W., Jr., and Banks, P. A. 1990. Measuring herbicide injury to soybeans using a hand-held, multispectral radiometer. Weed Sci. Vol. 38 (in press).
3. Ahlrichs, J. S., and Bauer, M. E. 1982. Relation of agronomic and multispectral reflectance characteristics of spring wheat canopies. Technical Report SR-P2-O4384, Laboratory for Applications of Remote Sensing, Purdue Univ., West Lafayette, IN. 26 pp.
4. Backman, P. A., and Crawford, M. S. 1984. Relationship between yield loss and severity of early and late leafspot diseases of peanut. Phytopathology 74:1101-1103.
5. Brenneman, T. B., and Csinos, A. S. 1988. Evaluation of experimental fungicides for control of peanut diseases. 1987. Fungic. Nematic. Tests 43:212.
6. Calpouzos, L., Roelfs, A. P., Madson, M. E., Martin, F. B., Welsh, J. R., and Wilcoxson, R. D. 1976. A new model to measure yield

losses caused by stem rust in spring wheat. Minn. Agric. Exp. Stn. Tech. Bull. 307. 23 pp.
7. Chiteka, Z. A., Gorbet, D. W., Knauft, D. A., Shokes, F. M., and Kucharek, T. A. 1988. Components of resistance to late leafspot in peanut. II. Correlations among components and their significance in breeding for resistance. Peanut Sci. 15:76-81.
8. Knauft, D. A., Gorbet, D. W., and Norden, J. A. 1988. Yield and market quality of seven peanut genotypes as affected by leafspot disease and harvest date. Peanut Sci. 15:9-13.
9. Lewis, A. E. 1984. Biostatistics. Van Nostrand Reinhold, New York. 198 pp.
10. Little, T. M. 1985. Analysis of percentage and rating scale data. HortScience 20:642-644.
11. Littrell, R. H., and Heath, M. 1985. Evaluation of fungicide treatments for control of leafspot and influence on pod yield. 1985. Fungic. Nematic. Tests 41:113.
12. MacKenzie, D. R., and King, E. 1980. Developing realistic crop loss models for plant diseases. Pages 85–89 in: Crop Loss Assessment. Teng, P. S. and S. V. Krupp, eds. Misc. Pub. 7, Minn. Agric. Ext. Stn. 327 pp.
13. Nutter, F. W., Jr., and Alderman, S. C. 1987. Use of late leaf spot disease gradients to evaluate disease assessment schemes for accuracy, precision, resolution, and speed. Phytopathology 77:1700.
14. Nutter, F. W., Jr. 1989. Detection and measurement of plant disease gradients in peanut using a multispectral radiometer. Phytopathology 79:958-963.
15. Nutter, F. W., Jr. 1990. Remote sensing and image analysis. In: Crop Pest Management to Improve Pest Management in Rice and Rice-based Farming Systems. Int. Rice Res. Inst., Los Banos, Philippines. (In press).
16. Nutter, F. W., Jr., and Littrell, R. H. 1985. Predicting yield responses of peanuts to various disease severity levels of late leafspot (*Cercosporidium personatum*) by measuring reflectance of sunlight from peanut canopies. Proc. Am. Peanut Res. Ed. Soc. 17:47.
17. Nutter, F. W., Jr., Littrell, R. H., and Pederson, V. D. 1985. Use of a low-cost multispectral radiometer to estimate yield loss in peanuts caused by late leaf spot (*Cercosporidium personatum*). (Abstr.) Phytopathology 75:502.
18. Nutter, F. W., Jr., and Pederson, V. D. 1985. Receptivity, incubation period, and lesion size as criteria for screening barley genotypes for resistance to *Pyrenophora teres*. Phytopathology 75:603-606.
19. Plaut, J. L., and Berger, R. D. 1980. Development of *Cercosporidium personatum* in three peanut canopy layers. Peanut Sci. 7:46-49.
20. Sharp, E. L., Perry, C. R., Scharen, A. L., Boatwright, G. O., Sands, D. C., Lautenschlager, L. F., Yahyaoui, C. M., and Ravet, F. W. 1985. Monitoring cereal rust development with a spectral radiometer. Phytopathology 75:936-939.
21. Sherwood, R. T., Berg, C. C., Hoover, M. R., and Zeiders, K. E. 1983. Illusions in visual assessment of Stagonospora leaf spot of orchard grass. Phytopathology 73:173-177.
22. Shokes, F. M., Berger, R. D., Smith, D. H., and Rasp, J. M. 1987. Reliability of disease assessment procedures: A case study with late leafspot of peanut. Oleagineux 42:245-251.
23. Shokes, F. M., Smith, D. H., and Littrell, R. H. 1986 Field evaluation of fungicides for management of peanut foliar diseases. Pages 212–216 in: Methods for Evaluating Pesticides for Control of Plant Pathogens. K. D. Hickey, ed. American Phytopathological Society, St. Paul, MN. 312 pp.
24. Subrahmanyam, P., McDonald, D., Gibbons, R. W., Nigam, S. N., and Nevill, D. J. 1982. Resistance to rust and late leafspot diseases in some genotypes of *Arachis hypogaea*. Peanut Sci. 9:6-10.
25. Steel, R. G. D., and Torrie, J. H. 1980. Principles and Procedures of Statistics—A Biometrical Approach. McGraw-Hill, New York. 633 pp.