Economic Evaluation of Fungicides for Control of Alfalfa Foliar Diseases

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ABSTRACT

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Benomyl, copper hydroxide, or mancozeb were applied to 10 consecutive cuttings of the alfalfa cultivar Phytor from 1983 through 1985 using various schedules. Disease severity at harvest was reduced by all fungicide:schedule combinations. Disease control improved as the number of applications per cutting was increased. All treatments except mancozeb or benomyl applied 10 days before harvest and all copper hydroxide treatments had higher yields than the control. Several treatments had higher stand densities than the control at the end of the study. Zero, one, two, or three applications of mancozeb at weekly intervals beginning after 10–14 days of regrowth were evaluated in 1985 on three cuttings of the alfalfa cultivars Raidor and Vernal. All fungicide treatments reduced area under disease progress curve and final disease severity. Dry matter yield of the control was lower than the fungicide treatments, which were not statistically different from each other. The most profitable treatment was a single application of mancozeb after 10–14 days of regrowth with a 215% return on investment and net marginal return of \$20.58/ha. Maximum yield reduction in an individual trial was 52% and mean loss to foliar pathogens over all trials was approximately 15%. In both studies, *Phoma medicaginis* and *Stemphylium botryosum* were the predominant pathogens with *Colletotrichum* and *Leptosphaerulina* spp. present at lower levels.

Fungicides are not widely used to manage foliar diseases of alfalfa (*Medicago sativa* L.) because they are perceived to be unprofitable and because of concerns about residue exposure to animals and humans (18). Investigations concerning crop losses caused by foliar pathogens of alfalfa indicate that fungicides could provide effective disease control and significantly increase hay yield. These yield increases range from 10 to 42% per cutting (14,21,26,27,31,32) and from 9 to 27% annually (34). Hay quality also has been improved by fungicide application (22,34). However, further research on application rates, timing, and frequency is necessary before the economic benefits of such a control method can be estimated.

Various rates of benomyl (8), thiabendazole (20), and other fungicides (1) have been evaluated. Rate effects on disease control were variable, but no beneficial effects on yield were reported.

Results from studies on frequency of fungicide application were contradictory. One application of mancozeb was compared with a weekly schedule throughout the regrowth period in Kansas (25). Higher individual cutting and annual yields resulted from the additional applications. Hart and Close (14), however, reported no differences in defoliation, leaf/stem ratio, or dry matter yields when they compared two applications of benomyl per cutting to a weekly schedule. They emphasized that proper spray timing in combination with timely harvesting was critical to achieve increased quality and yield of hay.

Stuteville and Sorensen (25) demonstrated the importance of fungicide application timing. Eight fungicide treatments involving one application per cutting were evaluated in each of four harvest periods. The number of treatments that increased yield was greatest in the first and fourth cuttings. Treatments in those tests were applied at least 25 days before harvest compared with application 7 and 17 days before harvests in the second and third cuttings, respectively.

The magnitude of yield response to fungicide application has been shown to vary with the fungicide, application schedule, pathogen(s), level of disease pressure, and environment. Yield gains reported by other researchers imply that fungicide use on alfalfa may be profitable, but more detailed work is needed to confirm this.

The objectives of this research were to: 1) determine the predominant fungi associated with foliar disease on alfalfa; 2) assess the levels of yield loss attributable to foliar disease; and 3) determine the economically optimal fungicide application frequency and timing for control of foliar diseases. A preliminary report has been published (7).

MATERIALS AND METHODS

Experiment 1. A stand of the alfalfa cultivar Phytor was established on a Drummer silty clay loam (fine-silty, mixed, mesic Typic Haplaquoll) at the Agronomy-Plant Pathology South

Farm, Urbana, IL, in the spring of 1982. Except for fungicide application, standard cultural practices were followed throughout the study (3). The experiment was designed as a randomized complete block with five replications of 12 treatments in plots 1.5 × 7.6 m. Treatments consisted of various combinations of three fungicides and four application schedules. Benomyl 50WP (1.1 kg/ha) and mancozeb 80WP (2.2 kg/ha) were applied 26 days; 10 days; 26 and 10 days; or 26, 18, and 10 days before harvest. Cupric hydroxide 77WP (2.2 kg/ha) was applied either 10 days or 26 and 10 days before harvest. A tank-mix of benomyl 50WP (1.1 kg/ha) and mancozeb 80WP (2.2kg/ha) was applied 26, 18, and 10 days before harvest. An untreated check was included in all trials.

Treatments were applied to each of 10 consecutive cuttings (trials) from 1983 through 1985 (second, third, and fourth in 1983; first, second, and third, in 1984; and first, second, third, and fourth in 1985). Fungicides were applied in 327 L/ha of water using a CO_2 pressurized back-pack sprayer with D5-23 hollow cone nozzles (Spraying Systems Co., Wheaton, IL) on 25.4-cm centers operated at 276 kPa and 1.4 m/sec. Triton B-1956 (Rohm and Haas Co., Philadelphia, PA) was used as a surfactant with all treatments at 313 μl/L.

Plots were evaluated for percent leaf area exhibiting disease symptoms without regard to causal organism 1 day before harvest of each trial. In the 1984 and 1985 trials, 10–30 leaflets were sampled from each control plot to determine the relative occurrence of fungal pathogens. Leaflets were surface-sterilized by submersion in 70% ethanol followed by 0.525% NaOCl, each for 60 sec. After two 60-sec rinses in sterile distilled water, leaflets were incubated in petri plate moist chambers for 5–7 days with 12 hr of light per day at 20–22 C. The adaxial leaflet surfaces were scanned using a dissecting microscope at 40× for the presence of fungal spores or fruiting structures. The incidence per leaflet of the predominant pathogens and percentage of leaflets with one or more pathogens were recorded. Isolates of the commonly observed fungi were periodically collected from leaflets, single-spored, and identified to confirm incidence data.

Stem length and defoliation index were determined from 10 stems randomly selected and sampled at ground level. Length was measured from the bottom of the stem to the terminal growing point of the main stem. Defoliation index was calculated as the length from the base to the first leaf attached directly to the main stem divided by total stem length.

Plots were harvested after approximately 35 days of regrowth, which corresponded to a crop growth stage of 1/10–1/4 bloom. A flail-chopper (Carter Manufacturing Co., Inc., Brookston, IN) was used to harvest a 0.9- × 5.8-m section from the center of each plot leaving 5–8 cm of stubble. Moisture content was determined from 10 subsamples of approximately 1,000 g each, which were weighed and dried to a constant weight in an oven at 65 C. Yield values corrected for plot size and moisture content were expressed in Megagrams/hectare of dry matter.

Stand density was determined after the first trial in 1983 and 1984 by randomly tossing a 51-cm-diameter circular frame three times into each plot and counting the number of plants with living crown buds encircled by the frame. Similar methods were used after the fourth harvest in 1985; however, plants were counted after they were removed from the soil with a shovel and only two randomly selected areas of each plot were sampled. Stand density values are reported as number of plants per square meter.

Data (except for plant density) were averaged over all harvests and subjected to analysis of variance. Treatments were compared using Waller-Duncan's Bayesian k-ratio least significant difference tests ($k = 100$). Single-degree-of-freedom contrasts also were made between groups of treatments (Table 1). Treatment groups were selected to detect response trends for application timing and specific fungicides.

Experiment 2. Experiments were established in 1985 on the second, third, and fourth harvests of 3-yr-old stands of Raidor alfalfa in Clinton Co., IL, and Vernal alfalfa in Champaign Co., IL. Soil type in these locations were Cisne silt loam (fine, montmorillonitic, mesic Mollic Albaqualf) and Proctor silt loam (fine-silty, mixed, mesic Typic Argiudoll), respectively. Treatments in all experiments consisted of zero, one, two, or three applications of mancozeb 80WP at 2.2 kg/ha made at weekly intervals beginning after 10–14 days of crop regrowth. Each treatment was replicated 10 times in a randomized complete block design in each of the six experiments. Plot size, fungicide application methodology, disease assessments, and yield determinations were as described previously. Disease evaluations were made at weekly intervals throughout the regrowth period of all experiments. Area under disease progress curve (AUDPC) was calculated using to the equation:

$$\text{AUDPC} = \sum_{i=1}^{n-1} [0.5(x_i + x_{i+1})][t_{i+1} - t_i]$$

where x_i = the percentage of foliar disease severity at the ith evaluation, t_i = time of the ith evaluation in days from the first evaluation date, and n = total number of disease evaluations. Incidence of the predominant fungal pathogens was determined from 75 leaflets as described previously.

Analysis of variance was performed as a split-plot design combined over locations (random effect) with cuttings and treatments (both fixed effects) as the main and subplots, respectively. Treatments were compared using Waller-Duncan's Bayesian k-ratio least significant difference tests ($k = 100$).

Economic evaluation. Economic comparisons between treatments in Experiment 2 were made as net marginal return relative to the untreated control with all yields adjusted to 15% moisture. Net marginal return was calculated from the formula: net marginal return = marginal return − marginal cost. Marginal return was the value of additional hay yield obtained due to treatment, and marginal cost was the additional production costs incurred due to treatment (fungicide and application costs). Marginal return was calculated using a hay value of $72.75/Mg ($66.00/ton), which was the average price in Illinois for the period 1981 through 1985 (4). Fungicide cost was estimated at $4.40/kg ($2.00/lb) of mancozeb 80WP based on a January 1986 survey of the principal manufacturers and local agrichemical distributors. An estimated cost of application of $8.03/ha ($3.25/acre) was determined by farm management specialists with the Illinois Cooperative Extension Service, Urbana, for the 1984–1985 season (15). This estimate was for custom field spraying and included

TABLE 1. Mean foliar disease severity, defoliation index, hay yield, and final stand density for groups of fungicide:application schedule treatments applied to ten consecutive harvests of Phytor alfalfa from 1983 to 1985

Treatment group	Foliar disease severity (%)	Defoliation index[a]	Hay dry matter yield (Mg/ha)	Final stand density (plants/m^2)
BE, ME[b]	4.0	0.46	4.02	81
BL, ML	4.8	0.46	3.84	67
B2, M2	2.7	0.44	4.08	90
B3, M3	2.2	0.43	4.20	103
CuL, Cu2	4.6	0.48	3.80	76
ML, M2	2.2	0.45	3.94	82
BE, BL, B2, B3	3.9	0.46	4.00	82
ME, ML, M2, M3	3.0	0.44	4.04	88
Single-degree-of-freedom contrast		Analysis of variance		
ME, BE vs ML, BL	**[c]	**	**	**
ME, BE vs M2, B2	**	ns	ns	ns
ML, BL vs M2, B2	**	*	**	*
M2, B2 vs M3, B3	*	ns	*	ns
ML, M2 vs CuL, Cu2	*	**	**	ns
BE, BL, B2, B3 vs Me, ML, M2, M3	**	**	ns	ns

[a] Defoliation index = length from stem base to lowest leaf attached to main stem/total stem length.

[b] Treatment abbreviations are a fungicide:application schedule combination. B, Cu, and M = benomyl, copper hydroxide, and mancozeb, respectively. E, L, 2, and 3 = application 26; 10; 26 and 10; and 26, 18, and 10 days before harvest, respectively.

[c] * and ** = contrast significant at $P = 0.05$ and 0.01, respectively. ns = contrast not significant ($P = 0.05$).

charges for equipment use, operator labor, mechanical power, and fuel. Total estimated marginal cost per application was $17.90/ha ($7.25/acre).

RESULTS

Experiment 1. The hot and dry 1983 growing season was unfavorable for foliar disease development and crop growth. The maximum disease severity in any cutting during 1983 was 3%. Consequently, responses to treatments were minimal. Because data from 1983 trials were included in the analysis, results and conclusions concerning treatment effects should be considered highly conservative.

Disease severity was reduced by all fungicide:schedule combinations evaluated (Table 2). Differences between treatments also were evident with improved disease control as the number of applications was increased. All single-degree-of-freedom contrasts between treatments grouped according to schedules were significant, indicating that infections were occurring throughout the regrowth period (Table 1). Mancozeb provided disease control superior to that of benomyl and copper hydroxide (Table 1).

Fungicide applications had no influence on plant height, but defoliation was significantly lower in all treatments except those involving cupric hydroxide (Table 2). Defoliation estimates for early and late applications were equal, and both were significantly higher than two application treatments (Table 1). Less defoliation occurred in plots treated with mancozeb than those where either benomyl or copper hydroxide were applied (Table 1).

All treatments except mancozeb or benomyl applied late in the regrowth period and the two copper hydroxide treatments yielded more than the control (Table 2). Increasing the number of fungicide applications was positively associated with yield. The maximum dry matter yield increase was 14% when three sprays of mancozeb tank-mixed with benomyl were made. Single early season spray treatments had 0.18 Mg/ha higher yield than the single late season applications but were not different from the two-spray schedule treatments (Table 1). Addition of a third spray approximately 18 days before harvest increased yields 0.12 Mg/ha relative to treatments where applications were made only 26 and 10 days before harvest (Table 1). Yields were higher in mancozeb-treated plots compared with copper hydroxide but single-degree-of-freedom contrasts between mancozeb and benomyl-treated plots were not significant (Table 1).

Plant densities averaged 115 and 91 plants per square meter for measurements taken after the first cuttings in 1983 and 1984, respectively. Treatment effects were not significant for either of these sampling dates. Stand density at the end of the study was influenced by treatments. Higher densities were maintained when benomyl or mancozeb were applied two or three times each regrowth period or as a tank-mix combination (Table 2). A single early season application of mancozeb also had a higher final plant density compared with the control. The late season spray treatment group had 14 and 23 fewer plants per square meter than the early and two-spray schedules, respectively, which were not different from each other (Table 1). Single-degree-of-freedom contrasts between fungicides with respect to final plant density were not significant.

Colletotrichum, *Leptosphaerulina*, *Phoma*, and *Stemphylium* were the fungi most frequently observed on leaflets from control plots. Twelve of the 16 *Colletotrichum* isolates were *C. destructivum* O'Gara and four were *C. dematium* (Pers. ex Fr.) Grove f. *truncata* (Schw.) von Arx (29,30). Single ascospore isolates in the *Leptosphaerulina* group were not identified to species but all 12 fit the generic description of Graham and Luttrell (11). Using the differential criteria of Boerema (6), 17 of the 18 *Phoma* isolates were identified as *P. medicaginis* var. *medicaginis*. All *Stemphylium* isolates had spore dimensions and morphology similar to those reported for *S. botryosum* (12,23,24,35).

In 1984 and 1985, *P. m. medicaginis* and *S. botryosum* were the most prevalent pathogens on Phytor (Table 3). *P. m. medicaginis* was the primary pathogen in the first harvest period. Its incidence decreased in subsequent cuttings in both years. The incidence of

TABLE 2. Effects of fungicide treatment on final stand density and mean final disease severity defoliation index and yield over 10 harvests of Phytor alfalfa from 1983 to 1985

Treatment abbreviation[a]	Final disease severity (%)	Defoliation index[b]	Dry matter yield per harvest (Mg/ha)	Final stand density (plants/m^2)
M+B3	1.1	0.37	4.26	124
BE	4.2	0.47	3.97	76
BL	5.2	0.46	3.85	66
B2	3.2	0.45	4.05	86
B3	3.0	0.45	4.18	104
CuL	5.2	0.48	3.73	72
Cu2	4.1	0.48	3.85	79
ME	3.9	0.46	4.08	87
ML	4.5	0.47	3.82	68
M2	2.2	0.43	4.11	96
M3	1.4	0.40	4.23	102
Con	7.3	0.50	3.71	64
BLSD[c] (k = 100)	0.5	0.02	0.15	17

[a]Treatment abbreviations are a fungicide:application schedule combination. B, Cu, and M = benomyl, copper hydroxide, and mancozeb, respectively. E, L, 2, and 3 = application 26; 10; 26 and 10; and 26, 18, and 10 days before harvest, respectively; and Con = untreated check.

[b]Defoliation index = length from stem base to lowest leaf attached to main stem/total stem length.

[c]Waller-Duncan's Bayesian k-ratio least significant difference.

TABLE 3. Incidence of fungi observed in microscopic examination of leaflets collected from untreated control plots of Raidor alfalfa in Clinton County, IL, and Phytor and Vernal alfalfa in Champaign County, IL, in 1984 and 1985

Variety	Sample date	Harvest period	*Colletotrichum* spp. (%)	*Leptosphaerulina* spp. (%)	*Phoma medicaginis* (%)	*Stemphylium botryosum* (%)
Phytor[a]	6-14-84	1	0	0	79	0
	7-19-84	2	2	3	70	62
	8-28-84	3	74	14	66	45
	5-29-85	1	4	0	93	38
	7-3-85	2	45	7	85	60
	8-9-85	3	51	25	48	21
	9-17-85	4	37	0	32	72
Raidor[b]	7-1-85	2	51	88	42	16
	8-5-85	3	27	63	33	11
	9-10-85	4	17	55	41	72
Vernal[b]	6-30-85	2	27	12	64	48
	8-19-85	3	24	39	47	89
	9-24-85	4	13	33	35	93

[a]50–150 leaflets examined per sample date.

[b]75 leaflets examined per sample date.

Leptosphaerulina spp. was never greater than 25%, and it was not observed in the first cutting in either year. The highest incidence of *Colletotrichum* spp. was observed in the third harvest of each year, but no other seasonal patterns were evident. In all cuttings, 79% or more of the leaflets were colonized by at least one of the predominant pathogens. At least 37% had signs of more than one pathogen except for the first cutting in 1984.

Experiment 2. Disease severity in the untreated control increased throughout the entire regrowth period in half of the trials (Fig. 1B, D, and E) and plateaued during the last two sampling dates in the other half (Fig. 1A, C, and F). These two general types of response were not associated with any particular cultivar, regrowth period(s), or level of disease pressure. Mancozeb applications reduced the rate of disease increase over time (Fig. 1A–F). Increases in the number of spray applications generally resulted in slower rates of disease increase.

Interaction effects were significant ($P \leqslant 0.01$) for final disease severity, AUDPC, and dry matter yield. However, because all fungicide treatments resulted in responses that differed significantly from the control for all variables in all trials and average response to the treatments are of interest, means for the pooled data are presented in addition to those for individual trials.

In the untreated control, final disease severity ranged from 7.3 to 20.2% and AUDPC values from 65 to 458 in individual trials (Table 4). Final severity and AUDPC were inversely related to the number of times that mancozeb was applied, but differences between treatments other than the control varied among trials. All fungicide treatments significantly reduced severity and AUDPC compared with the control but did not differ from each other when data were pooled over trials (Table 4). An exception was three applications of mancozeb having lower final disease severity than one application.

Dry matter yields in control plots were significantly lower than those in the treated plots in all trials (Table 4). Yield increases due to mancozeb application ranged from 8% for a single spray during the fourth harvest of Vernal to 52% for three applications on the second harvest of Raidor. Increasing the number of mancozeb sprays generally increased yield, but differences between the sprayed treatments were not always significant. An example is the yield response trends in trials during the third and fourth cuttings of Vernal. During the third cutting, environmental conditions favored infection throughout (Fig. 1E), and yields increased significantly from each additional mancozeb application (Table 4). During the fourth cutting, however, conditions were favorable only during the first 2 wk of regrowth, becoming very dry and unfavorable until harvest (Fig. 1F). The extreme nature of these conditions was reflected also by the unusually low yields for that cutting (Table 4). In this trial, yields from mancozeb-treated plots did not differ from each other. Generally, yield increases with additional sprays were not proportional to the number of sprays, indicating a diminishing return on disease control investment. When data were pooled over the six trials, all treatments had higher mean yields relative to the control (Table 4).

Trends in the incidence of pathogens varied considerably between cultivars (Table 3). *Leptosphaerulina* spp. were observed in relatively high frequencies (55–88%) on all sampling dates for Raidor, whereas incidence on Vernal was never higher than 39%. Five consecutive days of slow misting rain and high relative humidity at the Clinton County location immediately after the first harvest was ideal for rapid succulent regrowth of alfalfa and fungal infection. This is also reflected by earlier observation of initial symptoms (Fig. 1A) and higher final disease severity and AUDPC values (Table 4) than in the other trials. *Leptosphaerulina* spp. were the most common observed fungi in all Clinton County trials except the third harvest, where *S. botryosum* occurred on 72% of the leaflets. *Phoma medicaginis* and *S. botryosum* were the most prevalent pathogens in Champaign County on Vernal with the frequency of the former decreasing and the latter increasing with each subsequent sampling date (Table 3). The incidence of *Colletotrichum* spp. declined throughout the summer at both locations. Between 84 and 99% of the leaflets had signs of one or more pathogen, and 41–72% had signs of colonization by more

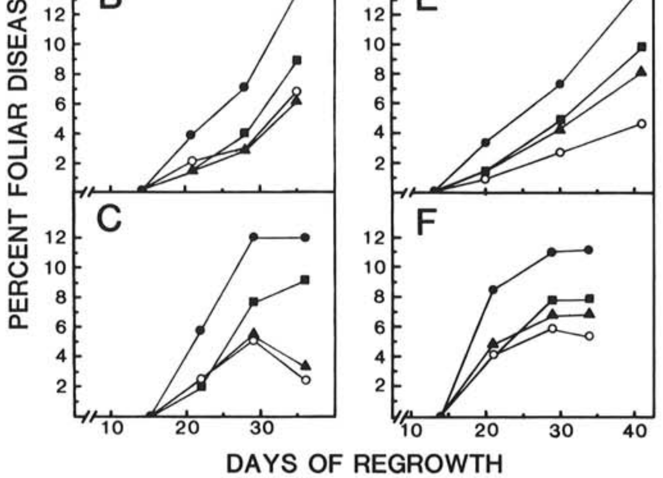

Fig. 1. Effect of number of mancozeb sprays on foliar disease severity for **A**, second; **B**, third; and **C**, fourth cutting of Raidor alfalfa in Clinton County, IL, in 1985 and **D**, second; **E**, third; and **F**, fourth cuttings of Vernal alfalfa in Champaign County, IL, in 1985. Mancozeb 80WP (2.2 kg/ha) applications made successively at weekly intervals after 10–14 days of regrowth. ●—● = untreated control, ■—■ = one application, ▲—▲ = two applications, and o—o = three applications.

TABLE 4. Effect of number of weekly mancozeb applications on foliar disease severity at harvest (%), area-under-disease-progress curve (AUDPC), and dry matter yield per cutting (Mg/ha) of Raidor and Vernal alfalfa in 1985

Number of applications[a]	Variety:harvest period combination[b]						
	R-2	R-3	R-4	V-2	V-3	V-4	Pooled
Percent[c]							
0	20.2	13.5	11.8	7.3	13.9	11.1	12.8
1	14.8	8.9	9.1	2.7	9.8	7.8	8.8
2	10.8	6.6	3.3	1.5	8.1	6.7	6.1
3	7.8	6.3	2.6	0.7	4.7	5.4	4.6
BLSD[d] (k = 100)	1.4	2.4	1.0	0.6	1.6	0.7	3.3
AUDPC[e]							
0	458	124	164	65	182	163	192
1	327	69	100	30	117	102	124
2	308	54	67	19	106	98	108
3	292	57	59	13	63	83	94
BLSD (k = 100)	22	20	8	6	15	8	37
Mg/ha							
0	3.16	2.69	2.44	3.80	3.08	1.78	2.81
1	4.07	3.07	2.73	4.11	3.50	1.92	3.27
2	4.25	3.14	2.89	4.14	3.81	1.96	3.35
3	4.80	3.17	2.88	4.17	4.00	1.99	3.48
BLSD (k = 100)	0.44	0.13	0.11	0.15	0.16	0.06	0.33

[a] Mancozeb 80WP (2.2 kg/ha) applied successively at weekly intervals beginning after 10–14 days of regrowth.

[b] R = Raidor, V = Vernal, and 2, 3, and 4 = second, third, and fourth harvest, respectively.

[c] Mean estimate for % leaf area in plot with disease symptoms over 10 or 60 (for pooled values) replications.

[d] Waller-Duncan's Bayesian k-ratio least significant difference.

[e] AUDPC was calculated according to the equation: AUDPC = $\sum_{i=1}^{n-1} [0.5(x_i + x_{i+1})][t_{i+1} - t_i]$ where x_i = the percentage of foliar disease severity at the ith evaluation, t_i = time of the ith evaluation in days from the first evaluation date, and n = total number of disease evaluations.

than one pathogen.

Economic evaluation. One application of mancozeb per cutting was profitable more consistently than the other two treatments (Table 5). In five of the six trials, a single early application of mancozeb had positive net marginal returns ranging from $6.36 to $58.23/ha. The only trial without profit was the fourth harvest of Vernal due to conditions unfavorable for disease development, which began when the first fungicide application was made. Profits for the two-spray schedule ranged from $1.85 to $55.39/ha and occurred in all but the second and fourth harvest trials on Vernal. The only trials where three applications produced a positive net return were the second and third harvests of Raidor and Vernal, respectively. In both cases, conditions favored infection throughout the regrowth period.

Mean yield increases over all trials ranged from 0.46 Mg/ha for a single spray to 0.67 Mg/ha for three applications of mancozeb. Although incremental increases in the number of mancozeb sprays improved marginal returns, when the marginal costs associated with each treatment were subtracted, an inverse relation between spray number and net marginal return resulted (Table 5). Despite providing the lowest gross return, a single application of mancozeb applied after 10–14 days of regrowth was the most profitable treatment with a 215% return on investment and a net marginal return of $20.58/ha ($8.33/acre).

DISCUSSION

Foliar disease on alfalfa in Illinois is associated with several fungi. *Phoma medicaginis* and *S. botryosum* predominate but *Colletotrichum* and *Leptosphaerulina* spp. also are important. The high frequency of multiple pathogens on leaflets shows that foliar pathogens of alfalfa occur as a complex. Environment seemed to regulate the relative proportions of the pathogens in the complex. Pathogen and disease development are reportedly associated with certain seasonal patterns and weather conditions (10). In these studies, *P. medicaginis* was observed most often early in the season, and, although incidence declined with time, it was still a substantial component of the fungal population in combination with *S. botryosum* later in the season. *Colletotrichum* and *Leptosphaerulina* spp. were present in lower levels throughout but lacked seasonal trends. The occurrence of favorable environmental conditions during a phase of rapid regrowth just after harvest in combination with frequent observation of fruiting structures of *Leptosphaerulina* in the second harvest of Raidor support the requirements for development of severe disease epidemics caused by *L. briosiana* as proposed by Leath and Hill (19). A more comprehensive understanding of environmental parameters in relation to variation in pathogen prevalence and epidemic progress may permit the development of predictive systems to improve the economic efficiency of decision-directed control measures such as

TABLE 5. Economic responses relative to the untreated control for the number of weekly mancozeb applications for control of foliar disease on the second, third, and fourth harvests of Raidor and Vernal alfalfa in 1985

Number of applications[a]	Individual trials with positive net marginal (no.)	Mean dry matter yield increase/cutting (Mg/ha)	Mean marginal return/cutting ($/ha)[c]	Mean net marginal return/cutting ($/ha)[b]	Mean return on investment (%)[d]
1	5	0.46	38.48	20.58	215
2	4	0.54	45.18	9.38	126
3	2	0.67	56.05	2.35	104

[a] Mancozeb 80WP (2.2 kg/ha) applied successively at weekly intervals beginning after 10–14 days of regrowth.

[b] Net marginal return = marginal return − marginal cost. Values are relative to the untreated control. Marginal cost per fungicide application = $17.90/ha and includes fungicide ($4.40/kg), equipment use, operator labor, mechanical power, and fuel costs.

[c] Marginal return is value of yield increase with control as the baseline and a hay value of $72.75/Mg at 15% moisture.

[d] Return on investment = marginal return/marginal cost.

fungicide application.

Foliar diseases reduce alfalfa production in Illinois. Yield reductions as high as 52% occurred in individual trials. Average yield losses to foliar pathogens were approximately 15%. These yield loss estimates represent a wide range of environments and are consistent with those reported by researchers at other locations (22,26,27,31,32,34). Environmental differences between trials were primarily responsible for the variation in yield loss to foliar pathogens. During the three trials in 1983, temperatures and rainfall were well above and below normal, respectively. As a result, disease pressure was low, with no yield loss in any of the trials. In contrast, the extended period of free moisture at the beginning of the second harvest of Raidor hastened initial symptom appearance by at least 5 days and enhanced disease development such that final disease severity, AUDPC, and yield reductions were the highest among all trials. In a pathosystem with a perennial host such as alfalfa and rather ubiquitious, facultative pathogens such as *P. medicaginis* and *S. botryosum*, environment is probably paramount in controlling the level of foliar disease and yield losses.

In this study, extending the period of fungicide protection with additional applications during the regrowth period improved disease control but did not necessarily increase yields and returns proportionally. This implies that infection generally occurs throughout the regrowth period, but protection early in the period affects yield most. The higher yields resulting from a single fungicide spray 26 days before harvest compared with the same treatment 10 days before harvest also support this hypothesis. Wilkens and Fick (33) inoculated plants with *P. medicaginis* in the greenhouse at 10, 17, and 24 days after regrowth started. They found that the day-10 inoculation resulted in the greatest yield reduction. This is probably related to the length of the incubation period and the level of symptom development necessary to cause a leaf to abscise. Late-season infections may not be as important as earlier ones because of the shorter time for symptom development and defoliation. Estimates for the incubation period (2,9,28) and disease severity necessary to cause abscission (5,16) have been reported for individual foliar pathogens under controlled conditions. These estimates may not apply to a complex of pathogens under field conditions. More precise information concerning incubation period and defoliation would be of considerable benefit in future attempts to evaluate and optimize fungicide application scheduling.

Repeated applications of fungicides to a stand of alfalfa for 3 yr reduced defoliation and increased stand longevity. Although this study was not designed to determine why fungicide application lengthened stand life, we propose two hypotheses. Because fungicides reduced disease severity and defoliation, the amount of photosynthesis may have been higher and more nonstructural carbohydrates available to improve winter hardiness. Nontarget effects of the fungicides, such as protecting the crowns from fungi, also may have contributed to lower levels of mortality and higher yields. Crown-rotting fungi are important factors associated with stand depletion of alfalfa (13,17). All treatments with higher plant density at the end of the experiment involved an application early in the regrowth period when spray penetration to the crowns would have been greatest. This supports the latter theory. However, additional sprays later in the regrowth period further improved final plant density supporting the photosynthetic area hypothesis. Neither hypothesis is mutally exclusive, and other possibilities must be considered.

Economic yield increases were obtained when 2.2 kg/ha of mancozeb 80WP was applied once per cutting after 10–14 days of regrowth. Environmental influences on the level of disease pressure and the benefits of fungicide protection affected the net marginal return in individual trials. However, a profit was realized in 80% of the trials with an average return on investment of 215%. This consistency and high rate of return indicate that consistent use of such a spray program would result in long-term profits even without incorporation of threshold or weather-related-action criteria to minimize unnecessary applications. Improved hay quality and stand longevity were two indirect economic benefits of fungicide use not included in our economic evaluation of fungicide use. Their consideration would further increase the profits realized from using such a method of foliar disease control. Including fungicides as a tank-mix with insecticides, which are commonly applied to alfalfa, also would increase returns by reducing application costs. Our evaluation of mancozeb shows that fungicide use can be profitable. The timing and frequency for application of other fungicides should be evaluated for most economical use.

Although fungicides effectively control foliar diseases and increase yield, quality, and stand life, they should not be relied on as the only method of control. Comparing the yield from the highest yield treatment and the most profitable treatment shows that optimum use of fungicides will prevent only about 68% of the total losses attributable to foliar diseases. Therefore, fungicide use should be integrated with other disease management tactics such as resistance, rotation, timely harvesting, and good general crop management in order for growers to realize the maximum economic return on their crop production investment.

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