Influence of Cultivar Resistance, Initial Disease, Environment, and Fungicide Concentration and Timing on Anthracnose Development and Yield Loss in Pickling Cucumbers

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Journal Series Paper 9526 of the North Carolina Agricultural Research Service, Raleigh 27695-7601.
The use of trade names does not imply endorsement of the products named or criticism of similar ones not mentioned.
We wish to thank C. W. Holloway, B. N. Ayscue, and F. C. Cumbo for assistance and Asgrow Seed Co., Petoseed Co. and Northrup King Co. for supplying seed.
Accepted for publication 3 July 1985 (submitted for electronic processing)

ABSTRACT

Thompson, D. C. and Jenkins, S. F. 1985. Influence of cultivar resistance, initial disease, environment, and fungicide concentration and timing on anthracnose development and yield loss in pickling cucumbers. Phytopathology 75:1422-1427.

Resistant cultivars of *Cucumis sativus* reduced the rate of anthracnose development caused by *Colletotrichum lagenarium* and allowed disease thresholds to be used to initiate fungicide applications. Action thresholds of 0, 1, 10, and 20% diseased tissue were used to initiate chlorothalonil applications on a 7-day or a weather-modified (WM) 7–14 day schedule. The WM schedule had three determinants, evaluated weekly, that initiated a spray application when any one of them occurred. The determinants were: no fungicide in the past 14 days; a rain event of 1 cm or greater in the past 7 days; and a 40% or greater probability of rain in the next 2 days. Chlorothalonil rates were 2.34, 2.34, and 1.17 kg/ha for cucumber cultivars Earlipik 14, Calypso, and Calico, respectively. Two spring, and four fall, crop environments and two levels of initial disease provided a wide range of conditions and disease development. Disease developed slowly in the spring crops and caused no yield loss. In the fall crops, yield loss was greatest; there were early and rapidly developing epidemics that within each test had the greatest area under the disease progress curve. Yield loss was proportional to cultivar susceptibilty. Inoculation of the central four to six plants resulted in less disease development than inoculation of the entire plot. Initial disease levels of 0.01 and 0.1% diseased tissue were not consistent in their effect on yield loss. The 10% action threshold resulted in some yield loss. In two of four fall crops, yield loss resulted only when no fungicide was applied. The WM application schedule had little effect on disease or yield, and saved from zero to one spray applications. Results of correlation analysis followed by factor analysis indicated that a high temperature (>32 C)–low disease determinant might have been useful in the WM schedule.

Additional key words: action thresholds.

Cultivars of cucumber, *Cucumis sativus*, have been released that possess resistance to the foliar diseases prevalent in the southeastern United States (12). Anthracnose, which is caused by *Colletotrichum lagenarium* (Ell. & Halst.) Pass., is a major foliage disease of cucumbers. Anthracnose and other leafspot diseases may become an economic problem during the early stages of growth but are more frequently a problem when plants are senescing or damaged from multiple harvests. Resistance to anthracnose reduces disease development (D. C. Thompson, *unpublished*). When environmental conditions are favorable, however, epidemics can cause 60% yield loss (C. W. Averre, *personal communication*). Present production recommendations in North Carolina are for weekly fungicide applications beginning when anthracnose or any other leafspot is observed (7). Studies have not been done to combine the effects of resistance in these cultivars with reduced fungicide applications to decrease fungicide usage without incurring yield loss.

Fungicide usage in potato plantings was reduced by using fewer applications or lower rates of application (1–3). The number of applications also can be reduced by using disease thresholds to delay the initiation of the spray program. Disease thresholds can then be followed by either a regular spray schedule or a disease forecast modified spray schedule such as BLITECAST for late blight on potatoes (10) or FAST for early blight on tomatoes (11). Fry (4) concluded that, to provide reliable control, disease thresholds must be accompanied with a forecast of disease for polycyclic pathogens with high rates of increase. When disease is first observed in a rapidly developing epidemic there is a substantial amount of undetectable infection that has not completed the incubation period. Grower reaction to a disease threshold must be faster in a rapidly developing epidemic than in a slow epidemic. Jones (9) concluded that by the time target spot caused by *Corynespora cassiicola* (Berk. & Curt.) Wei was first observed on the cucumber cultivar Poinsett, it was too late for initiation of fungicide applications. Resistance levels of cucumber cultivars that are currently being grown may reduce the rate of anthracnose development enough to allow adequate reaction time.

Polycyclic foliar pathogens that do not require specific events, such as rain, for dispersal and infection may require the prediction of undetected disease for the use of disease thresholds. *Colletotrichum* spp. require splashing water for dispersal and their occurrence may be distinct enough so that a disease threshold will be reached between two dispersal events. At present, no forecasting algorithm is available for anthracnose or any of the other leafspot diseases on cucurbits.

At least two major environmental factors may influence anthracnose epidemics. First, conidia of *C. lagenarium* are water dispersed; and second, anthracnose is not considered to be a problem at temperatures above 30 C (5,8).

This study was undertaken to determine how anthracnose severity and yield of pickling cucumber were influenced by using different disease thresholds for initiation of fungicide applications on either a 7-day or a weather modified (WM) 7- to 14-day schedule, when initial disease severity and cultivar resistance were varied. Environmental conditions were monitored to identify parameters that are associated with anthracnose development that could be incorporated into a weather-modified fungicide application schedule.

MATERIALS AND METHODS

Field experiments. Experiments were performed in six crop environments with different cultural conditions and treatments. As the experiments progressed over the years, treatments were modified to gather additional information. On 13 July 1981, the moderately resistant cucumber cultivar Calypso (Asgrow Seed Co.,

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Kalamazoo, MI) was planted at the Horticultural Crops Research Station, Clinton, NC (CL). Plots were six rows wide and 6.1 m long with two unplanted rows and 1.5-m alleys between plots. Rows at CL were 1.0 m apart (center to center) in all tests. The inner four rows were harvested. The experimental design was a randomized complete block design with five replications. Inoculum was sprayed on entire plots at 25,000 conidia per milliliter, 15 ml per plot. Two rows of beans *Phaseolus vulgaris* L. 'Contender' were planted between plots in both directions to reduce interplot interference.

In the spring of 1982 at CL, Calypso was planted on 6 May. Plots were six rows wide and 6.1 m long with two unplanted rows and 1.5-m alleys between plots. The inner four rows were harvested. The experimental design was a randomized complete block with four replications. Inoculum was applied either to the entire plot or to the central four to six plants at 25,000 conidia per milliliter, 15 ml per plot.

In the summer of 1982, cultivars Calypso and highly resistant Calico (Petoseed Co., Inc., Saticoy, CA) were planted on 23 July at CL and at the Horticultural Crops Research Station, Castle Hayne, NC (CH). Plots were four rows wide and 3.7 m long with two unplanted rows and 2.4-m alleys between plots. The inner two rows were harvested twice weekly. At CH, rows were 1.1 m on center. Inoculum was applied to the whole plot at 25,000 or 200,000 conidia per milliliter, 15 ml per plot. At CL, the experimental design was a split block with repeats, and two replications. At CH, a randomized complete block design with two replications was used.

In 1983, cultivars Calypso, Calico, and susceptible Earlipik 14 (Northrup King Co., Minneapolis, MN) were planted at CL on 31 May and 4 August. Plots were four rows wide and 3.7 m long with two unplanted rows and 2.4-m alleys between plots. The inner two rows were harvested. The experimental design was a split block with six replications. Inoculum was applied to whole plots at 25,000 conidia per milliliter, 15 ml per plot.

General cultural conditions. Cultivars were overseeded into raised, shaped beds 0.5 m across the top and later thinned to a density of 49,000-59,000 plants per hectare. Fertilizer applications were based on soil analysis and herbicides and insecticides applied as needed (7). Overhead sprinkler irrigation was applied as needed to provide 2.5 cm of water per week. Hand harvesting was done twice weekly until individual plots had 50% diseased tissue or no marketable fruit were being produced. Fruit were graded mechanically by diameter into three grades and culls (1 1.9–2.9 cm, 2 2.9–3.8 cm, 3 3.8–5.1 cm, and culls >5.1 cm). Dollar value of yield was calculated by using U.S. $0.132, 0.066, 0.044, and 0.022 per kilogram for grades of 1, 2, 3, and culls, respectively, as recommended by the Pickling Cucumber Improvement Committee, St. Charles, IL. Yield in tonnes per hectare was the sum of grades 1, 2, 3, and culls.

Inoculum. *C. lagenarium* Race 1 (No. 52609, American Type Culture Collection, Rockville, MD) (6), which was used in all inoculations, was maintained at 24 C on potato-dextrose agar. Conidia were removed from 4- to 10-day-old cultures growing on green bean agar, by gently swirling distilled water in the petri plate. A haemacytometer was used to calibrate spore suspensions. Plants were inoculated at the three- to five-leaf stage between 1800 and 2100 hours. Conidial suspensions were sprayed onto plants at 137.9 kPa (20 psi) while the operator walked at 4.8 kmh (3 mph) unless otherwise noted. An uninoculated plot was included in all tests.

Fungicide applications. Fungicide applications were initiated at different disease thresholds during the six crop environments (Tables 1, 2, and 3). Action thresholds were 0, 1, 10, and 20% diseased leaf tissue. When the action threshold was reached, chlorothalonil (0.5 kg/L; SDS Biotech Corp., Cleveland, OH) was

TABLE 1. Area under disease progress curves (AUDPC) of anthracnose on pickling cucumber cultivars with different levels of resistance and initial disease severities when fungicide (chlorothalonil) applications were initiated at different disease action thresholds on either a 7-day or a weather-modified (WM) 7- to 14-day schedule in North Carolina

Season and location[a]	Cultivar[b]	Initial disease[c]	Area under disease progress curves[d] following fungicide application at disease action threshold of: 0	1%	1%WM[e]	10%	10%WM[e]	20%	20%WM[e]	No fungicide	LSD ($P = 0.05$)
1981 F/CL	Calypso	0	335	434		525		533		684	108
1982 S/CL	Calypso	Low	7	13		140	116	129	163	119	71
		High		24		231	238	247	258	258	
1982 F/CL	Calypso	Low	121	169		283	224	281		250	51
		High		176		266	274	277		287	
	Calico	Low	131	163		255	228	220		260	
		High		183		265	241	249		241	
1982 F/CH	Calypso	Low	171	236		326	224	250		223	99
		High		345		280	321	248		144	
	Calico	Low	44	57		117	66	49		89	
		High		70		118	85	113		140	
1983 S/CL	Calypso	Low	17	65	60	117	115	81		95	87
	Calico	Low	12	46	42	74	59	71		63	
	Earlipik 14	Low	17	114	144	221	208	219		239	
1983 F/CL	Calypso	Low	90	188	205	324	348	355		355	126
	Calico	Low	85	121	138	236	220	223		223	
	Earlipik 14	Low	82	244	242	456	463	441		422	

[a] S = Spring, F = Fall, CL = Clinton, and CH = Castle Hayne.
[b] Chlorothalonil (5,090 g/L) was applied to cultivars Earlipik 14, Calypso, and Calico at the rate of 1.17, 1.17, and 0.59 kg/ha, respectively.
[c] Low and high initial disease severities resulted from inoculation with a suspension of 25,000 conidia per milliliter on the central four plants or whole plots, respectively, in spring 1982. In all other tests, suspensions of 25,000 or 200,000 conidia per milliliter were applied to whole plots for low and high initial disease severities, respectively.
[d] Calculations were performed until the first plot reached 50% or greater diseased tissue in each test.
[e] The WM 7- to 14-day spray schedule had three determinants, evaluated every 7 days, any one of which could initiate applications: no fungicide in the past 14 days; rainfall even greater than 1 cm in the past 7 days; or probability of rainfall in the next 2 days 40% or greater in National Weather Service forecasts.

TABLE 2. Yield of pickling cucumber cultivars with different levels of anthracnose resistance and initial disease severities when fungicide (chlorothalonil) applications were initiated at different disease action thresholds on a 7-day or a weather-modified (WM) 7- to 14-day schedule in North Carolina

Season/ Location[a]	Cultivar[b]	Initial disease[c]	Yield (t/ha) following fungicide application at action thresholds of: 0	1%	1%WM[d]	10%	10%WM[d]	20%	20%WM[d]	No fungicide	LSD ($P = 0.05$)
1981 F/CL	Calypso	0	21	20		18		21		11	6
1982 S/CL	Calypso	Low	46	49		42	47	47	43	45	ns
		High		48		43	45	42	43	42	
1982 F/CL	Calypso	Low	47	51		38	35	36		41	10
		High		54		51	44	46		37	
	Calico	Low	43	49		33	39	37		44	
		High		48		46	42	43		40	
1982 F/CH	Calypso	Low	13	12		7	5	7		5	5
		High		13		11	10	12		8	
	Calico	Low	21	19		15	14	13		14	
		High		16		18	17	18		18	
1983 S/CL	Calypso	Low	41	42	40	38	35	40		39	8
	Calico	Low	40	42	38	40	41	36		38	
	Earlipik 14	Low	39	38	39	35	33	35		33	
1983 F/CL	Calypso	Low	30	29	31	28	27	27		22	7
	Calico	Low	23	24	25	22	22	22		19	
	Earlipik 14	Low	24	31	23	18	20	21		16	

[a] S = Spring F = Fall, CL = Clinton, CH = Castle Hayne.
[b] Chlorothalonil (5,090 g/L) was applied to Earlipik 14, Calypso, and Calico at the rate of 1.17, 1.17, and 0.59 kg/ha, respectively.
[c] Low and high initial disease severities resulted from inoculation with a suspension of 25,000 conidia per milliliter on the central four plants or whole plots, respectively, in spring 1982. In all other tests, suspensions of 25,000 or 200,000 conidia per milliliter were applied to whole plots for low and high initial disease severities, respectively.
[d] The WM 7- to 14-day spray schedule had three determinants, evaluated every 7 days, any one of which could initiate applications: no fungicide in the past 14 days, rainfall event greater than 1 cm in past 7 days, or probability of rainfall in the next 2 days 40% or greater in National Weather Service forecasts.

TABLE 3. Value of pickling cucumber cultivars with different levels of anthracnose resistance and initial disease severities when fungicide (chlorothalonil) applications were initiated at different disease action thresholds on a 7-day or a weather modified (WM) 7- to 14-day schedule in North Carolina

Season and Location[a]	Cultivar[b]	Initial disease[c]	Crop value ($/ha[d]) following fungicide applications at disease action thresholds of: 0	1%	1%WM[e]	10%	10%WM[e]	20%	20%WM[e]	No fungicide	LSD ($P = 0.05$)
1981 F/CL	Calypso	0	1,009	973		929		1,081		589	286
1982 S/CL	Calypso	Low	2,091	2,172		2,000	2,132	2,192	2,157	2,172	322
		High		2,136		2,045	2,170	2,006	2,030	2,045	
1982 F/CL	Calypso	Low	3,020	3,142		2,547	2,133	2,289		2,662	563
		High		3,367		3,250	2,843	2,795		2,462	
	Calico	Low	2,805	3,126		2,246	2,500	2,409		2,902	
		High		3,025		2,950	2,651	2,797		2,606	
1982 F/CH	Calypso	Low	804	693		422	347	478		345	297
		High		775		653	598	671		483	
	Calico	Low	1,155	1,080		881	776	739		802	
		High		896		1,022	943	1,062		1,036	
1983 S/CL	Calypso	Low	2,210	2,282	2,115	2,137	1,974	2,197		2,130	366
	Calico	Low	1,959	2,183	1,928	2,077	2,110	1,930		2,051	
	Earlipik 14	Low	1,872	1,840	1,834	1,800	1,681	1,734		1,681	
1983 F/CL	Calypso	Low	1,560	1,588	1,635	1,571	1,479	1,507		1,280	323
	Calico	Low	1,202	1,280	1,383	1,217	1,179	1,201		1,028	
	Earlipik 14	Low	1,204	1,211	1,249	1,009	1,146	1,164		890	

[a] S = Spring, F = Fall, CL = Clinton, CH = Castle Hayne.
[b] Chlorothalonil (5,090 g/L) was applied to Earlipik 15, Calypso, and Calico at the rate of 1.17, 1.17, and 0.59 kg/ha, respectively.
[c] Low and high initial disease severities resulted from inoculation with a suspension of 25,000 conidia per milliliter on the central four plants or whole plots, respectively in spring 1982. In all other tests, suspensions of 25,000 or 200,000 conidia per milliliter were applied to whole plots for low and high initial disease severities, respectively.
[d] Yield was weighted by using values of $13.20, $6.60, $4.40, and $2.20/100 kg for grades of 1 = 1.9–2.8 cm diameter, 2 = 2.8–3.8 cm, 3 = 3.8–5.1 cm, and culls = greater than 5.1 cm, respectively, which is the pricing system adopted by the Pickling Cucumber Improvement Committee, St. Charles, IL.
[e] The WM 7- to 14-day spray schedule had three determinants evaluated every 7 days, any one of which could initiate applications: no fungicide in the past 14 days; rainfall event greater than 1 cm in the past 7 days; and probability of rainfall in the next 2 days 40% or greater in National Weather Service forecasts.

applied on either a 7-day or a WM 7- to 14-day schedule. The WM 7- to 14-day schedule had three determinants that were evaluated every 7 days; the occurrence of any one of these initiated a fungicide application. The determinants were: no fungicide in the past 14 days, precipitation of 1 cm or greater in the past 7 days; and a probability of rain in the next 2 days of 40% or greater (United States National Weather Service, Raleigh, NC). Chlorothalonil was applied to the decreasingly resistant cultivars Calico, Calypso, and Earlipik 14, at the rates of 1.17, 2.34, and 2.34 kg/ha, respectively, based upon fungicide equivalency established in previous tests (1-3, and D. C. Thompson, *unpublished*). Either a hand-held or a tractor-mounted boom was used to apply fungicide in 935 L/ha (100 gpa) at 689.4 kPa (100 psi) through Tee Jet hollow cone nozzles (D4 disk, 45 core; Spraying Systems Co., Wheaton, IL). A no-fungicide control treatment was included in all tests.

Disease evaluation. A pictorial disease index was used to evaluate disease severity twice weekly beginning when lesions became visible. The index was subdivided into nine intervals: 0, 0–1, 1–3, 3–6, 6–12, 12–25, 25–50, 50–75, and 75–100% diseased tissue. Older and younger foliage were rated separately and their proportions were weighted differentially as plants grew. This may have resulted in a decrease in percent disease severity when plants grew. Areas under disease progress curves (AUDPC) were calculated by averaging two consecutive disease evaluations, multiplying this average by the number of days between the two observations, and summing these values from the first to the last observation. This summation was done for each plot in a test until one of the plots reached 50% diseased tissue, when all calculations for that test ended. Calculations included the data from the evaluation when 50% diseased tissue was first observed. This provided a better comparison within tests. Logistic intercepts and slopes were calculated by using data from time of inoculation until the last harvest.

Weather data. Microclimatic data were collected with CR 21 Microloggers (Campbell Scientific, Logan, UT) of the standard one-scan-per minute type. Most parameters were stored on cassette tapes as 60-min average, sum, or sample. Temperatures were measured with Fenwal model UUT51J1 thermistors (Model 101 from Campbell Scientific). Free moisture was detected with Dewsensor wetness sensors (model 731 from Campbell Scientific). Rain and irrigation were monitored with tipping-bucket range gauges (Sierra-Misco, from Campbell Scientific) at a height of 150 cm.

Wet- and dry-bulb temperatures were measured at a height of 40 cm with aspirated (2–3 m/sec) thermistors placed in insulated polyvinylchloride pipe. Aspiration was done with a 12-VDC electric motor (Dayton Model 2M272, Dayton Mfg. Co., Chicago, IL) attached to a 7.6-cm-diameter fan blade. Within-canopy temperatures were measured with nonaspirated thermistors at a height of 10 cm, under plant leaves. Relative humidity (RH) was calculated from wet- and dry-bulb temperatures. Wetness sensors were painted three to four times with flat green acrylic latex paint (Weatherbeater, Meadow Green 077, Sears, Roebuck and Co., Chicago, IL) and mounted horizontally at heights of 20 and 30 cm on wooden stakes placed within and outside of the plant canopy, respectively.

The Statistical Analysis Systems (SAS Institute, Inc., Cary, NC) general linear models analysis program was used to manipulate, analyze, and plot the data. Fisher's least significant differences in AUDPC, and yield as weight and dollar value in each crop environment, were calculated from the analysis of variance sums of squares for the interaction between replications, action threshold, cultivars, and initial disease levels. Linear regression was used to calculate logistic slopes and intercepts. Factor analysis with a Varimax (orthogonal) rotation was employed to analyze a matrix of environmental and disease variables (Table 4).

TABLE 4. Factor analysis of anthracnose on cucumbers and environmental variables by using a Varimax (orthogonal) rotation

Variables	Factor 1	Factor 2	Factor 3	Communality (h^2)
Initial disease[a]	0.93[b]	0.18	0.13	0.91
Final disease	0.96	0.22	0.08	0.98
Disease increase	0.92	0.27	−0.03	0.93
Area of disease increase[c]	0.94	0.27	0.02	0.96
Logistic rate of increase	0.31	−0.15	−0.43	0.30
Degree days (base 10–32 C)	−0.05	−0.30	0.87	0.86
Leaf wetness (hr)	0.26	0.01	0.54	0.36
Leaf wetness-rain[d]	0.00	0.53	−0.58	0.63
Relative humidity (hr)	−0.47	−0.09	0.41	0.40
Day >32 C	−0.15	−0.30	0.74	0.66
Days >32 C 1-10 days[e]	−0.65	0.33	0.25	0.59
Rain 1–10 days	0.02	−0.34	−0.73	0.65
Rain 5–15 days	−0.16	−0.61	−0.53	0.67
Irrigation 1–10 days	0.20	0.92	0.02	0.88
Irrigation 5–15 days	0.11	0.85	−0.16	0.76
Rain + Irrigation 1–10 days	0.18	0.92	0.03	0.87
Rain + Irrigation 5–15 days	0.08	0.85	−0.13	0.75
Variance	0.05	0.04	0.03	

[a] Disease was evaluated twice weekly and variables calculated from sequential observations.
[b] Factor loading (correlation between the variable and the factor).
[c] Area of disease increase = [(final disease) − (initial disease)] [days between observations]/2.
[d] Hours of leaf wetness associated with rain events >1 cm in the 20 days prior to interval.
[e] Sum of days >32 C, rain, or irrigation in either 10 days prior to interval (1–10 days) or in 10 days prior to 5 days before interval (5–15 days).

RESULTS

Disease development. Disease development during the six cropping seasons was highly variable and provided a wide range of epidemics. The most severe epidemic occurred during the fall of 1982 at CH when disease developed early and rapidly (Fig. 1). The severity of epidemics at CL decreased in the following order: fall 1982, fall 1981, fall 1983, spring 1983, and spring 1982.

The AUDPC of early, rapidly developing epidemics in the fall of 1982 at CH and CL were not as large as the slightly slower, later 1981 and 1983 fall crop epidemics (Table 1). The AUDPC of slow epidemics in the spring crops were similar to the fast epidemics of the 1982 fall crop at the higher disease thresholds; however, AUDPC was significantly less at the lower action thresholds. These similarities of AUDPC between very fast and slow epidemics in different crop environments resulted in a better separation of epidemics within tests than between tests because the 50% diseased

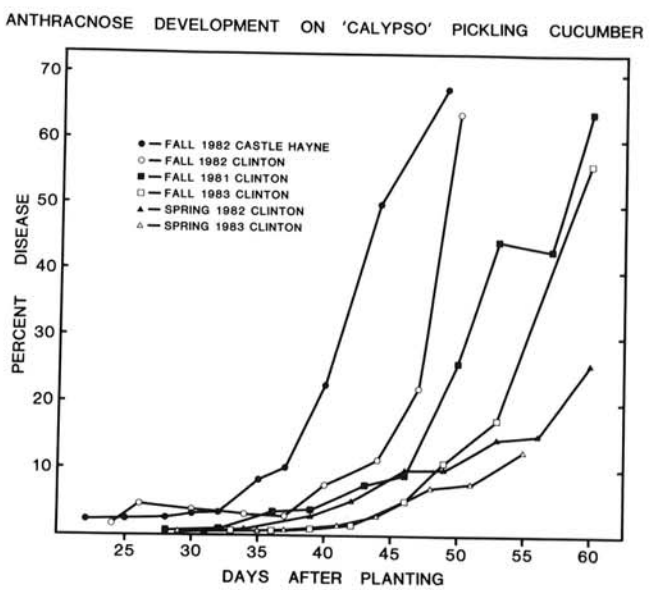

Fig. 1. Disease progress curves of anthracnose on pickling cucumber cultivar Calypso grown without fungicide applications in six crop environments in North Carolina.

tissue cut-off for calculation of AUDPC came early and late, respectively.

Cultivar Calico frequently had less disease than Calypso at the higher action thresholds and both were usually less diseased than Earlipik 14 (Table 1). Inoculation of the central four to six plants resulted in less disease than whole-plot inoculation when disease was allowed to progress to the higher action thresholds in the spring of 1982. Low and high levels of whole-plot inoculation were inconsistent in their effects on disease development in the fall of 1982.

Frequently, significantly ($P=0.05$) less disease developed when 0 and 1% disease were used to initiate fungicide applications compared to 10% or greater thresholds (Table 1). The WM 7-14 day schedule did not result in a significant increase in disease when compared to the 7-day schedule at the same action threshold.

Number of fungicide applications were reduced from a range of five to seven, when applied to continually cover the plants, to a range of zero to three when a 10% or greater action threshold was used. Using the WM schedule saved from zero to one application compared to the standard 7-day schedule. Differences in cultivar resistance resulted in a savings of from zero to one application. Initial disease severity levels either had no effect or were not consistent in modifying the number of fungicide applications.

Yield. Yield of cucumber, in both weight (Table 2) and dollar value (Table 3), was greatest in the fall of 1982 at CL. Spring crops were similar to the fall 1982 crop at CL in weight but much lower in value. The fall crops of 1981, 1982 at CH and 1983 were similar and approximately half of that occurring in the spring crops and fall 1982 crop at CL. Significant ($P= 0.05$) yield loss, in both weight and value, occurred in the high-yielding fall 1982 crop at CL and in the other lower-yielding fall crops; however, no yield loss occurred in the spring crops. The least significant differences in yield weight and value averaged 24% of the yield in the uninoculated, fungicide-treated plots. Coefficients of variation in yield ranged from 11.0 to 67.6 and from 6.46 to 93.7 and averaged 24.7 and 25.7 in weight and value, respectively.

During the fall crops of 1981 and 1983, yield loss occurred when no fungicide was applied to Calypso and Earlipik 14, but no yield loss occurred with Calico. Calypso sustained yield loss in both weight and value in the fall of 1982 at CL and CH in approximately half of the treatments in which 10% or greater action thresholds were used. Calico sustained yield loss less frequently than Calypso but in a similar pattern. Yield loss was expressed less frequently in dollar value than in weight. Frequently, low initial disease resulted in significant yield loss when high initial disease did not, but the opposite also occurred. The WM schedule had no effect on yield as fruit weight and had an infrequent and inconsistent effect on fruit value at the 10% action threshold.

Correlation of a single disease observation with yield had the highest correlation coefficients during the period of 40–45 days after planting. The regression of yield and percent yield loss against AUDPC or logistic intercept and slope resulted in low coefficients of determination (R^2) values unless crop season was considered. AUDPC values within crop seasons explained 95 and 62% of the variability in yield as weight and fruit value, respectively. Logistic intercept and slope within crop seasons explained 95 and 58% of the variability in weight and dollar value, respectively.

Environment. Factor analysis is a multivariate statistical technique used to determine the structure of the linear dependencies among a set of variables. The technique considers the variability within the data to be the result of interdependence among the variables (communality) and the result of the innate variability unique to each variable. Communality is further partitioned into a set of orthogonal factors that represent hypothetical determinants of the correlations among the variables. Factor analysis provides an estimate of the correlation between each variable and each factor (factor loading). This information is presented in the form of a factor matrix and can be used to group the variables according to their importance in each factor. Factor analysis reduced 12 environmental variables and five disease variables to three factors (Table 4). Factor 1 showed a negative relationship between four disease variables and the environmental variable of hours of RH >85% during an interval of observation and the number of days when the maximum temperature >32 C in the 10 days prior to an observation. Factor 2 showed a positive association between leaf wetness associated with rain, irrigation, and irrigation plus rain, during an interval. These variables, however, were negatively associated with rain. Factor 3 contained a positive association between rain, leaf wetness associated with rain, and the logistic rate of disease increase in one group. In another group, degree days (10–32 C), hours of leaf wetness, hours of RH >85%, and the number of days with maximum temperature >32 C during an interval between observations were positively associated. The variables found in one group, however, were negatively related to those found in the other group.

Correlation coefficients between anthracnose and environmental variables were generally low. Significant negative correlations ($P=0.01$) consistently occurred between disease increase variables and days >32 C and days >32 C in the 10 days prior to an interval.

Comparison of factor analysis and correlation coefficients suggested that rain was positively associated with disease increase. Temperatures >32 C had a negative association with disease increase and may restrict disease development. During the fall crop of 1981 at CL, frequent rains >1 cm occurred during the early part of the epidemic; however, they were followed by temperatures >32 C. Rain (1.5 cm) at 39–40 days after planting was not accompanied by high temperatures, and anthracnose increased significantly (Fig. 1). Immediately following inoculation of the spring 1982 crop at CL, heavy rains occurred and the cucumber plants developed rapidly. After lesions became visible, rains >1 cm fell at 3- to 4-day intervals and were not accompanied by high temperatures. The cucumber plants appeared to grow faster than the rate at which anthracnose developed and little disease occurred. Irrigation was frequently required during the fall of 1982 at CL. Rain (2.1 cm) fell 42 days after planting, temperatures were moderate and anthracnose increased.

The most severe epidemic occurred in the fall 1982 crop at CH and was associated with rains 24–25 and 36–37 days after planting followed by temperatures <32 C. Irrigation was frequently used during the spring of 1983 at CL. When rain occurred it was followed by temperatures >32 C. The fall crop of 1983 at CL required frequent irrigation. Rains occurred 26–29 days after planting that were associated with temperatures >32 C. Rain (3.2 cm) fell 41 days after planting followed by temperature <32 C and the epidemic developed rapidly. The more severe of these six epidemics were associated with moderate rains followed by temperatures <32 C early in the crop season.

DISCUSSION

It is generally assumed that disease development must be minimized to prevent yield loss. In this study, suppression of anthracnose development with fungicides was frequently unnecessary to prevent yield loss. Resistant cultivars made it possible for cucumbers to be grown with only occasional yield loss. Monitoring of disease development provided a means of detecting conditions that had been favorable for disease development and a mechanism for determining when action thresholds for the initiation of fungicide applications had been reached. The frequent occurrence of low levels of anthracnose and other leafspot diseases makes it worthwhile to use high action thresholds for initiating fungicide applications. A 10% action threshold provided substantial savings in fungicide applications and substantial disease control while significant yield loss occurred in two of four fall crop environments but only in a few treatments. The more resistant cultivar sustained less yield loss. This frequency of yield loss may be too great for some growers to take the risk. The 7- to 14-day WM fungicide schedule did not alter disease development or yield compared to the standard 7-day schedule, but saved only from zero to one spray application.

The WM schedule was based on rain as a mechanism of pathogen dispersal and fungicide weathering. We also found that high temperatures (>32 C) reduced anthracnose development when they followed rain and were negatively correlated with disease. This

demonstrates that the incorporation of a high-temperature determinant into the WM schedule algorithm could improve fungicide efficiency.

Multiple-point comparisons were made between anthracnose and yield with disease in the form of AUDPC and logistic intercepts and slopes, and yield as weight and value. Earlier and more rapid epidemics, and those epidemics with larger AUDPC within a test, resulted in greater yield loss. Single-point analyses identified 40–45 DAP as the time when disease had the most influence on yield. Protecting plants prior to this stage from substantial disease development may prevent the buildup of inoculum and subsequent disease increase and yield loss. Presently, many growers apply a fungicide/insecticide combination on a 5- to 7-day schedule starting at flowering stage for the control of leafspot diseases and pickleworm, *Diaphania nitadalis* Stoll., respectively. Early epidemics cause the most yield loss. To measure the potential for substantial disease development, plants should be monitored for anthracnose and other leafspots prior to blossoming.

The high R^2 for the regression of disease on yield as weight (kg/ha) within a test shows a high relationship between disease and the ability of the plants to produce fruit biomass. Lower R^2 for fruit value (dollars per hectare) could result from diseased plants producing small fruit of high value. In a previous report, narrow-sense heritabilities for fruit value and fruit number in a monoecious pickling cucumber population were estimated to be 0.19 and 0.17, respectively (13). These low heritabilities indicate a large amount of environmental variability for yield.

Our work was done on small plots in which the entire plot could be observed. Sampling techniques to assess disease severity, and the use of disease thresholds for initiation of fungicide applications should also be evaluated in large fields. The pictorial disease index used in this study will be a valuable tool in determining disease severity.

The efficiency of pesticide usage should increase through the use of indicators and predictors of pest problems. Two examples in cucumber production are the Cucumber Pest Alert (14) that reports pickleworm moth flights, and the disease thresholds combined with 7- to 14-day WM fungicide application schedules tested in this study. The 7- to 14-day WM schedule determinants are easily assessed without using complex equipment, making the predictor easily adopted. Predictors that require the use of relative humidity, leaf wetness, temperature and rainfall sensors, and their integration for disease prediction increase the complexity and cost of disease prediction. This requires a substantial investment of capital, and trust in the predictor. The risk aversion and capabilities of a grower will determine whether these practices are actually adopted.

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