Continuous Hours of Leaf Wetness as a Parameter for Scheduling Fungicide Applications to Control White Rust in Spinach

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ABSTRACT

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The timing of fungicide applications to control white rust of spinach based on continuous hours of leaf wetness (CHLW) was evaluated in three experiments. Chlorothalonil applications after 6, 12, and 18 CHLW were compared with an unsprayed check and a 10-day fixed schedule in both fall and spring plantings of the spinach cultivar Iron Duke. The 6- and 12-CHLW treatments were as effective as the fixed schedule in reducing white rust in both plantings. The potential for using 12, 18, and 24 CHLW to time metalaxyl sprays compared with a 7-day schedule under multiharvest conditions was investigated using the cultivar Chinook. Under these conditions, the 12-CHLW treatment also provided the same level of control as the fixed schedule but required five fewer applications. The rate of disease progression as influenced by metalaxyl applications based on 12, 18, and 24 CHLW was also studied. Although the incidence of white rust increased in unsprayed, 18-, and 24-CHLW plots, similar levels of disease control resulted from the 12-CHLW treatment and the fixed schedule.

Additional key words: *Albugo occidentalis, Peronospora effusa, Spinacea oleracea*

Texas leads the nation in spinach production, with more than 4,000 ha (13). White rust (caused by *Albugo occidentalis* G. W. Wils.) and downy mildew or blue mold (caused by *Peronospora effusa* Grev. ex Desm.) are the major spinach diseases in Texas (2,5). Both organisms have similar environmental requirements for infection and sporulation, including temperatures of 4–16 C and the presence of free surface moisture on a vigorously growing host (9–11). Historically, white rust has been managed through crop rotation and use of protective fungicides, whereas downy mildew has been controlled with vertical (monogenic) resistance (4). In the absence of resistant cultivars, a 5- to 7-day protective fungicide program initiated at the fourth-true-leaf stage and continuing until harvest is suggested. Knowledge of the role of environmental factors in disease initiation and development is important so that spray schedules can be refined to reduce the frequency of applications.

The literature contains many examples of fungi that require a specific time length of free surface moisture to successfully infect a susceptible host (1,6,7,12). Thomas (15) demonstrated that five to six continuous hours of leaf wetness (CHLW) were required for development of downy mildew in cantaloup (*Pseudoperonospora cubensis* (Berk. & Curt.) Rostow) despite the presence of inoculum and favorable temperatures. For Alternaria leaf blight (*Alternaria cucumerina* (Ellis & Everh.) Elliot), eight continuous hours were required (16). Disease control strategies have been proposed in which the duration of the wet period is the key parameter in determining timing of fungicide applications (8,12,16). Raabe and Pound (10) found that the spinach white rust fungus required free surface moisture for sporangial germination. This indicated that leaf wetness could be monitored to facilitate control of this fungus. This study was designed to evaluate several CHLW durations for effectiveness in timing fungicide applications to control white rust.

MATERIALS AND METHODS

Three experiments were conducted at the Texas A&M University Agricultural Research and Extension Center at Uvalde. Each experiment was arranged as a randomized complete-block design with four replicates. Plots consisted of four beds, each 3.9 × 6.1 m, with two plant rows per bed. The center two beds served as the treatment area and the outer two beds as buffers. Plant stands were thinned to a maximum population of 2.1×10^5 plants per hectare. The fixed-application schedule was initiated at the fourth-true-leaf stage. Daily leaf wetness was monitored from this time onward. When specific wetness durations occurred, fungicides were applied the next day. In this study, a leaf wetness period consisted of a time frame beginning and ending at noon over two consecutive days. Leaf wetness was recorded using a Belfort Instruments leaf wetness hygrothermograph (Belfort Instruments, Baltimore, MD). The sensing string of the recorder was placed about 5 cm above the bed surface between a double row of plants. Hemp-string sensors were found more suitable than systems based on electrical resistance grids (ERGs) in pretrial testing. Although ERGs may better reflect leaf wetness on the smooth surface

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of onion leaves (8), wetness of savoyed spinach leaves was more closely mimicked with the hemp string. Fungicides were applied with a Mini-Ulva hand-held sprayer (Micron Corporation, Houston, TX) calibrated to deliver 46.8 L/ha.

Experiment 1. Seeds of the spinach cultivar Iron Duke (susceptible to white rust and race 3 of downy mildew) were planted on 12 October and 10 December 1981 for fall and spring tests, respectively. Treatments consisted of an unsprayed check, a 10-day fixed-application schedule, and applications after 6, 12, and 18 CHLW. Chlorothalonil (Bravo 500) at 1.17 kg a.i./ha was applied. Treatment efficacy was determined by harvesting 40 plants at 30-cm increments (20/bed from each of the center two beds per replicate), alternating between plant rows. Marketable-sized leaves (about 30 cm^2 or larger) were stripped from each plant and sorted into symptomatic and asymptomatic lots. The fall planting was indexed for white rust on 12 December and the spring planting on 9 March.

Experiment 2. Seeds of the cultivar Chinook (susceptible to white rust and resistant to race 3 of downy mildew) were planted on 10 October 1982. The subsequent crop was grown for multiple harvest evaluation of treatment effectiveness. Treatments evaluated were the same as in experiment 1 with the following exceptions: the 6-CHLW treatment was replaced with 24 CHLW, the systemic fungicide metalaxyl (Ridomil 2E) at 0.14 kg a.i./ha was substituted for the protectant chlorothalonil, and the fixed-interval sprays were reduced from 10 to 7 days. At harvest maturity, 20 plants were removed at 60-cm increments using sampling and indexing techniques similar to those employed in experiment 1. The remaining plants were cut back to about 5 cm and allowed to regrow twice. Treatments were indexed on 21 December, 18 February, and 21 March.

Experiment 3. This experiment was conducted to determine the rate of disease development within treatments and to examine the influence of race 3 downy mildew susceptibility on treatment response. Iron Duke, a cultivar susceptible to race 3 of downy mildew, was planted on 23 January 1983. Treatments similar to those employed in experiment 2 were applied in this experiment. Disease progression was determined by weekly sampling of 10 plants per treatment. Treatment effectiveness was determined at harvest from a 20-plant sample obtained on the final sampling date.

Table 1. Effectiveness of white rust control in spinach cultivar Iron Duke as influenced by chlorothalonil applications based on continuous hours of leaf wetness

	Fall planting (1981)		Spring planting (1982)	
Treatments[a]	Diseased leaves[b] (%)	No. of sprays	Diseased leaves (%)	No. of sprays
10-Day schedule	7.9	3	2.3	5
6 Continuous hours	13.5	2	1.0	4
12 Continuous hours	8.0	2	1.0	4
18 Continuous hours	48.7	1	0.8	3
Unsprayed	42.8	0	41.1	0
LSD ($P = 0.5\%$)	14.7	···	5.4	···

[a] Spray applications on the 10-day schedule were initiated at the fourth-true-leaf stage; 1.17 kg a.i./ha of chlorothalonil was used for disease control. Sprays were applied in the other treatment when the appropriate leaf wetness durations occurred (time frame beginning and ending at noon over two consecutive days). If the wetness durations were satisfied, a fungicide application was made the next day.

[b] Percentages of diseased leaves were determined on 20 plants per treatment per 6.1-m bed, from each of the center two beds per replicate per treatment plot at 30-cm increments, alternating between the double plant rows per bed.

RESULTS AND DISCUSSION

In the fall planting of experiment 1, the 10-day fixed schedule resulted in 7.9% disease incidence on marketable-sized leaves compared with 42.8% on the unsprayed check (Table 1). About 49% of the marketable leaves harvested from the 18-CHLW plots were diseased, whereas fewer than 14% diseased leaves were found in the 6- and 12-CHLW plots (Table 1). The one application to 6- and 12-CHLW plots on 20 November after a 13-CHLW period had a significant effect ($P = 0.05$) on reducing subsequent disease development. The two applications required by the 6- and 12-CHLW treatments were equally as effective as the three applications required by the fixed schedule ($P = 0.05$). Similar results were obtained with the spring planting, except the 18-hr treatment also afforded control. We believe the effectiveness of the 18-hr duration in the spring test was due to the longer, colder growing season in the spring planting. Because low temperatures tend to retard both plant growth and white rust development (9,10,14), fewer favorable infection periods occurred. As in the fall, one less application was required with 6 and 12 CHLW than with the fixed schedule. As indicated by the percentage of diseased leaves in the unsprayed checks (42.8% fall and 41.1% spring), sufficiently high levels of disease were present to evaluate the treatments.

Eight sprays were applied during the two planting dates of 1981–1982 using the 10-day fixed schedule. Six applications were required when fungicides were applied after 12 CHLW. A 25% fungicide spray reduction over the two plantings was achieved without significantly reducing white rust control.

To assess CHLW spray savings achievable in a typical multiharvest Texas season, spinach plots in experiment 2 were grown for 120 days and harvested three times. Thirteen applications were required for season-long white rust control using the fixed schedule compared with eight applications using a 12-CHLW treatment (Table 2). Significant levels of white rust were not observed in

Table 2. Effectiveness of total season white rust control in spinach cultivar Chinook as influenced by metalaxyl applications based on continuous hours of leaf wetness

	First harvest (21 December 1982)		Second harvest (18 February 1983)		Third harvest (21 March 1983)		
Treatments[a]	Diseased leaves[b] (%)	No. of sprays	Diseased leaves (%)	No. of sprays	Diseased leaves (%)	No. of sprays	Total no. of sprays
7-Day schedule	0	5	0	5	0.0	3	13
12 Continuous hours	0	3	0	4	0.3	1	8
18 Continuous hours	0	2	0	3	0.0	0	5
24 Continuous hours	0	0	0	0	3.2	0	0
Unsprayed	0	0	0	0	13.1	0	0
LSD ($P = 0.05\%$)	NS	···	NS	···	3.2	···	···

[a] Spray applications on the 7-day schedule were initiated at the fourth-true-leaf stage; 0.14 kg a.i./ha of metalaxyl was used for disease control. Sprays were applied in the other treatments when the appropriate leaf wetness durations occurred (time frame beginning and ending at noon over two consecutive days). If the wetness durations were satisfied, a fungicide application was made the next day.

[b] Percentages of diseased leaves were determined on 20 plants per treatment per 6.1-m bed, from each of the center two beds per replicate per treatment plot at 60-cm increments, alternating between the double plant rows per bed. Planting date: 10 October 1982.

experiment 2 until the third harvest date. The final harvest of the unsprayed check resulted in 13.1% diseased leaves compared with 0.3, 0.0, and 3.2% diseased leaves in the 12-, 18-, and 24-CHLW plots and 0.0 for the 7-day schedule. Total sprays applied during the season were 13, 8, 5, and 0 for the 7-day schedule and 12-, 18-, and 24-CHLW treatments, respectively. Consequently, a 39% reduction in spray applications was achieved with the 12-CHLW compared with the 7-day schedule.

White rust disease progression, daily wet periods, and fungicide application dates for experiment 3 are presented in Figure 1. White rust lesions were not observed until the third sampling date (18 March). However, increased sporulation was observed the following week in all plots except the 12-CHLW and the fixed-schedule treatments. At harvest (25 March), about 19, 17, and 13% diseased leaves were found in the unsprayed check, 24-, and 18-CHLW treatments, respectively. Only 3% diseased leaves were detected in the 12-CHLW and none in the fixed-schedule plots. This difference was not significant ($P = 0.05$).

The absence of race 3 resistance in Iron Duke resulted in a high incidence of downy mildew in experiment 3 (Fig. 2). Downy mildew developed 6 wk after planting (true leaf initiation) and increased in severity through 11 March. A reduction in downy mildew incidence occurred thereafter. Although downy mildew and white rust have similar environmental requirements for infection, slight crucial differences in CHLW periods and temperature tend to favor the development of one over the other. Although the temperature range for both diseases is about 4–16 C (10,11), at 4 C, downy mildew appears to be favored, whereas at 16 C, white rust is favored (1,10). Also, the CHLW required by downy mildew is about 2 hr (11) as opposed to 6–12 hr for white rust (9,10). Slight changes in weather conditions during experiment 3 may have been responsible for early downy mildew development followed by white rust. Weekly mean high temperatures (WMHT) for 1 February–28 March were 11.9, 14.8, 18.6, 18.2, 24.2, 18.7, 18.1, and 17.8 C. The WMHT of 24.2 C for 1–7 March may have coupled with the 12 CHLW on 3 March and resulted in the diseased leaves recorded in treatment plots on 18 March (Fig. 2). According to the criteria of Raabe (9), an incubation period of 12 days with sporulating lesions apparent on 15 March were estimated from the prevailing temperatures. Site competition from downy mildew may have contributed to the slow white rust development in this study. As rapid plant growth occurred, more tissue area became available, providing new sites on which white rust could develop.

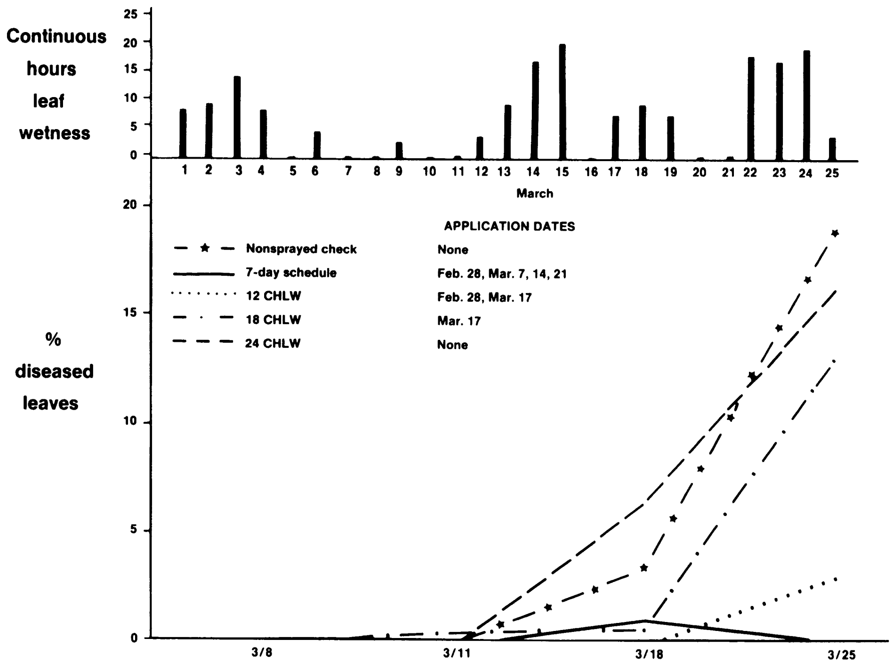

Fig. 1. Effectiveness of white rust control in spinach cultivar Iron Duke as influenced by metalaxyl applications based on continuous hours of leaf wetness in the spring of 1983.

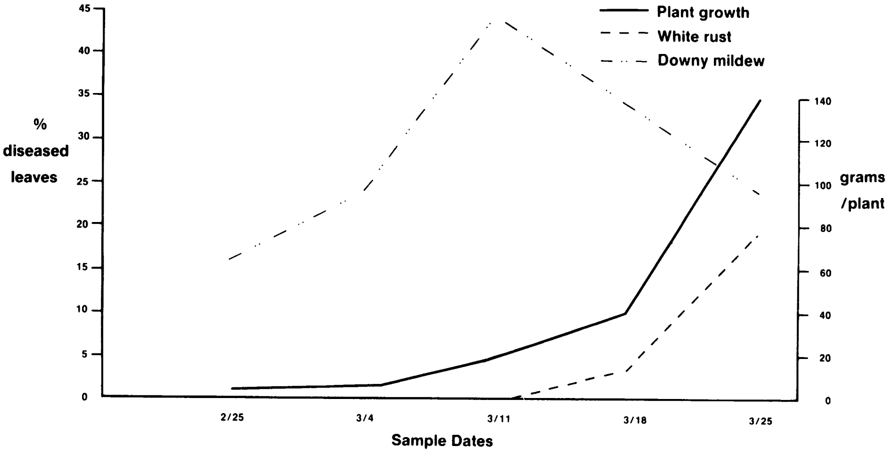

Fig. 2. Plant growth and disease progression for white rust and downy mildew on unsprayed spinach cultivar Iron Duke in the spring of 1983.

Godfrey (3) suggested a practical means of applying daily weather records to time fungicide applications for control of downy mildew of cantaloup. Monitoring of CHLW can be used in such a manner to manage spinach white rust provided a downy mildew-resistant cultivar is available. Because of the potential severity of both white rust and downy mildew in Texas, an effective disease control program must be approached in one of the following manners: 1) use of cultivars resistant to both causal organisms; 2) use of cultivars resistant to one organism plus a chemical control program effective against the other; 3) use of a chemical effective against both organisms; or 4) use of two chemicals, one effective against white rust and one against downy mildew. Currently, the spinach cultivars adaptable to Texas fresh-market production do not possess adequate levels of white rust resistance (2). In addition, the development of race 3 of downy mildew in 1977 negated the resistant sources previously used and resulted in increased reliance on chemical control of this disease. With the identification of several sources of race 3 resistance in 1982 (5), the potential for resistance to control downy mildew in spinach is again encouraging. Because of the difficulties associated with breeding horizontal (multigenic) resistance against white rust and the limited availability of sources of resistance, it is speculated that the second approach mentioned will be used by the Texas industry for some time. Monitoring of CHLW may become a valuable tool in strengthening this approach to spinach disease control. The potential exists to refine the CHLW system by superimposing other climatic variables, such as weekly mean high temperatures (WMHT) and incident solar radiation.

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LITERATURE CITED

1. Cohen, Y., and Rotem, J. 1969. The effects of lesion development, air temperature and duration of moisture periods on sporulation of *Pseudoperonospora cubensis* in cucumbers. Isr. J. Bot. 18:135-140.
2. Dainello, F. J., Heineman, R. R., and Jones, R. K. 1983. Relative white rust resistance and adaptability of spinach varieties in Southwest Texas. Tex. Agric. Exp. Stn. Prog. Rep. 3878.
3. Godfrey, G. H. 1954. Cantaloupe downy mildew in the lower Rio Grande Valley of Texas and its relation to relative humidity. Plant Dis. Rep. 38:616-619.
4. Jones, R. K., and Dainello, F. J. 1982. Occurence of race 3 of *Peronospora effusa* on spinach in Texas and identification of sources of resistance. Plant Dis. 66:1078-1079.
5. Jones, R. K., and Dainello, F. J. 1983. Efficacy of metalaxyl and metalaxyl tank mixes in controlling *Albugo occidentalis* and *Peronospora effusa* on spinach (*Spinacea oleracea*). Plant Dis. 67:405-407.
6. Langenburg, W. J., Sutton, J. C., and Gillespie, T. J. 1977. Relation of weather variables and periodicities of airborne spores of *Alternaria dauci*. Phytopathology 67:879-883.
7. Miller, M. E. 1975. Environmental factors associated with the spread of purple blotch of onions. (Abstr.) Proc. Am. Phytopathol. Soc. 2:25.
8. Miller, M. E., and Amador, J. A. 1981. Leaf wetness hours over onion fields in the lower Rio Grande Valley of Texas. Tex. Agric. Exp. Stn. Misc. Publ. 1482. 12 pp.
9. Raabe, R. D. 1951. The effect of certain environmental factors on the initiation and development of the white rust disease of spinach. Ph.D. dissertation. Univ. Wis., Madison. 63 pp.
10. Raabe, R. D., and Pound, G. S. 1952. Relation of certain environmental factors to initiation and development of the white rust disease of spinach. Phytopathology 42:448-452.
11. Richards, C. 1938. Downy mildew of spinach and its control. N.Y. Agric. Exp. Stn. Bull. 718.
12. Rotem, J., and Reichart, I. 1964. Dew—a principal moisture factor enabling early blight epidemics in a semiarid region of Israel. Plant Dis. Rep. 48:211-215.
13. Texas Department of Agriculture. 1982. Texas Vegetable Statistics. Tex. Crop Livestock Rep. Serv. 48 pp.
14. Thomas, C. E. 1970. Epidemiology of spinach white rust in South Texas. (Abstr.) Phytopathology 60:588.
15. Thomas, C. E. 1977. Influence of dew on downy mildew of cantaloups in South Texas. Phytopathology 67:1368-1369.
16. Thomas, C. E. 1983. Fungicide applications based on duration of leaf wetness periods to control Alternaria leaf blight of cantaloup in South Texas. Plant Dis. 67:145-147.