Control of White Rust of Spinach with Partial Resistance and Multiple Soil Applications of Metalaxyl Granules

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ABSTRACT

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Efficacy of zero, one, two, or three soil applications of metalaxyl fungicide for control of white rust disease of spinach (*Spinacia oleracea*), caused by *Albugo occidentalis*, was determined on a susceptible and a partially resistant cultivar. Metalaxyl on both cultivars delayed the development of initial white rust symptoms but did not reduce the rate of disease progress. The relative reduction of white rust from metalaxyl soil applications was greater on the susceptible cultivar than on the resistant cultivar. White rust was less severe on the untreated resistant cultivar than on the susceptible cultivar receiving three applications of metalaxyl.

White rust caused by *Albugo occidentalis* G.W. Wils. is a major foliage disease of spinach (*Spinacia oleracea* L.) in many production areas of the United States (3,7,12). Primary infection is initiated from soilborne oospores (18). Oospores splashed onto plant surfaces by rainfall or overhead irrigation germinate and infect the plant through open stomata (17). Secondary infection results from airborne sporangia discharged from lesions initiated by oospores or sporangia (16).

Environmental conditions and inoculum density influence white rust severity (8,16,17). When disease incidence is low, partial resistance, i.e., small effect, polygenic, and nondifferential (11), in spinach cultivars such as Fall Green, Coho, and Ambassador can provide acceptable white rust control without fungicides for an entire season (F. J. Dainello and M. C. Black, *unpublished*). When disease incidence is higher, significant crop loss occurs in spinach cultivars with partial resistance in the absence of fungicides. This is similar to potato late blight in resistant potato cultivars (10).

Before the release of spinach cultivars with partial resistance, white rust was managed by foliar protectant fungicides, including ethylene bisdithiocarbamate (EBDC) (3,8). Changes in pesticide regulations in the United States and Canada have eliminated these compounds from spinach disease control programs.

Metalaxyl has efficacy against oomycete fungi in the order Peronosporales (1,4,5, 14,20), including species that cause downy mildew (*Peronospora effusa* (Grev.) Tul.) and white rust of spinach (13). However, metalaxyl efficacy against white rust in resistant spinach cultivars has not previously been tested. In lettuce (*Lactuca sativa* L.), metalaxyl was shown to supplement horizontal resistance to downy mildew in an additive manner (20).

The first label in the United States for metalaxyl on spinach was a temporary Texas state label for application of a granular formulation at planting. Reasons for one application in the seed furrow at planting included a concern that metalaxyl tolerance might develop after multiple foliar applications (4,5), the lack of a suitable broad-spectrum fungicide for a tank mix, avoidance of application costs, and efficient uptake of metalaxyl by roots. This commercial practice has provided 40–60 days of protection against the spinach white rust fungus and was determined to be more rate-effective than preplant bed-spray applications (9).

In another study, a single soil application of metalaxyl protected hops from infection by *Pseudoperonospora humuli* (Miyabe & Takah.) G.W. Wils. for up to 2 mo (15). However, the spinach growing season ranges from 60 to 120 days for fresh market types and from 90 to 150 days for processing types, resulting in crop vulnerability to white rust after the initial protection provided by the at-planting soil application. Another consideration is the removal of this translocated fungicide by multiple harvests. Subsequent soil applications of metalaxyl have not been studied to determine whether this use pattern would provide extended crop protection.

The objective of this study was to determine the efficacy of multiple soil applications of metalaxyl for season-long control of white rust and to examine how this might be influenced by partial resistance in spinach.

MATERIALS AND METHODS

The study was conducted on a Uvalde silty clay loam soil known to be infested with *A. occidentalis*. A split-plot design with four replicates was used to evaluate treatments. Levels of partial resistance to white rust were whole plots (susceptible and resistant proprietary cultivars, Hy-S and Hy-R, respectively), and subplots were the number of metalaxyl soil applications (zero, one, two, or three). Subplots consisted of four raised beds (3.9×6.1 m) with two seed rows per bed. The center two beds were treated, and the outer two untreated beds served as treatment buffers and spreader rows for white rust. Seeding rate was approximately 2.1×10^5 seeds per hectare. The study was conducted twice,

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with planting dates of 31 October 1986 and 5 November 1987. Standard cultural practices for spinach production in the Texas Winter Garden were followed (7).

Metalaxyl (Ridomil 5G) at 112 g a.i./ha was placed in a band in the seed furrow using a Gandy applicator (model S902 EM, Gandy Company, Owatonna, MN). Plots receiving two applications were re-treated 30 days after planting (DAP) by banding the metalaxyl granules 5 cm deep and 15 cm toward the furrow side of each plant row. Plots receiving three applications were similarly treated 30 DAP and again after the first harvest.

Efficacy was assessed by collecting 20 plants per plot at 30-cm intervals. Marketable-sized leaves (30 cm^2 or larger) were stripped from each plant and sorted into symptomatic and asymptomatic lots, and the percent diseased leaves was calculated (7). Additionally, the percent leaf area with lesions was determined in season 1 by sorting 60 mature leaves per plot into appropriate classes using diagrams developed with an area meter (Landa Instruments, Inc., Lincoln, NE) (Fig. 1). Six leaves were systematically sampled at 10 sites at 60-cm intervals along the bed, alternating between the two seed rows. Mature leaves were collected at approximate row cross-section positions of 0, 45, 90, 135, and 180°. The average percent leaf area with lesions was then calculated using class frequencies and the midpoint value between classes.

In the first test, white rust was assessed on a weekly basis beginning with the first evidence of visible sporulation (12 December 1986) and continuing until harvest (28 January 1987). Weekly assessments were resumed on the regrowth (11 February 1987) and continued until the second harvest (4 March 1987). For the second test, treatment efficacy was determined only at each harvest (9 March 1988 and 11 April 1988).

RESULTS

Percent leaves with visible sporulation at first harvest are presented as means of two seasons because significant interactions ($P = 0.05$) were not detected between seasons and metalaxyl or between seasons and cultivars. At second harvest, significant season interactions occurred and data are therefore presented for each season. Disease progress and percent leaf area with visible sporulation were determined only for the first test.

The untreated partially resistant cultivar, Hy-R, had 30% fewer leaves with visible sporulation than the untreated susceptible cultivar, Hy-S, at first harvest (Fig. 2A). A single treatment of metalaxyl applied in the seed furrow to Hy-S resulted in a significant ($P = 0.05$) decrease (38% vs. 24%) in percent infected leaves as compared with untreated Hy-S. A second metalaxyl application at 30 DAP further reduced the number of infected leaves to 18% in the Hy-S; this reduction was not significant, however. White rust at first harvest of the partially resistant Hy-R was not significantly reduced by one or two metalaxyl applications.

Disease incidence at second harvest in the first season ranged from 29% infected leaves in the untreated Hy-S to less than 1% in Hy-R receiving three metalaxyl treatments (Fig. 2B). A single metalaxyl treatment applied in the seed furrow significantly reduced (14% vs. 29%) the percent infected leaves when compared with untreated Hy-S. No further disease reduction was noted with additional fungicide applications. Disease was not significantly reduced in Hy-R by metalaxyl treatment in season 1 (Fig. 2B).

Flower stalks had not developed at second harvest of the 1986 season. Disease evaluation was delayed in season 2 because of unfavorable weather. A high proportion of plants had initiated flowering by second harvest.

Disease incidence in all treatments at second harvest of season 2 exceeded 50% (Fig. 2C). Single applications of metalaxyl did not reduce the percent infected leaves in either cultivar. Three

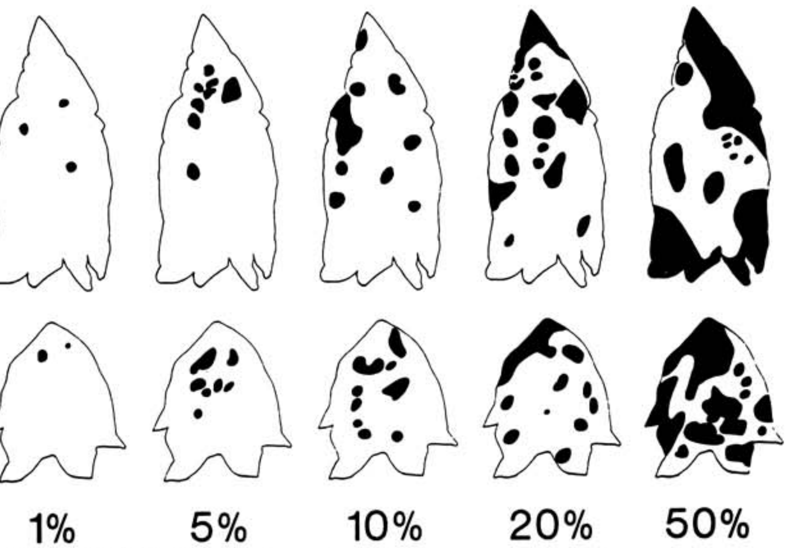

Fig. 1. Spinach leaf area diagrams used to estimate percent area of the abaxial leaf surface with white rust lesions caused by *Albugo occidentalis.*

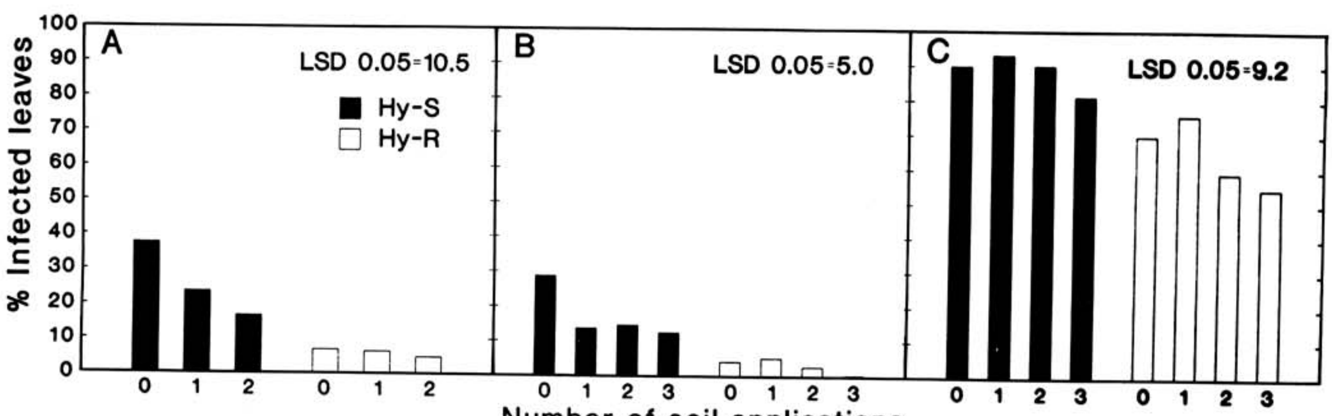

Fig. 2. Influence of multiple metalaxyl applications, susceptible cultivar Hy-S, and partially resistant cultivar Hy-R on white rust disease of spinach: **(A)** Treatment efficacy was pooled over both seasons at first harvest. Spinach was allowed to regrow in both seasons and efficacy was again evaluated in **(B)** season 1 and **(C)** season 2. The LSD values presented are appropriate for comparing any two metalaxyl application means within cultivars.

applications, however, significantly reduced percent infected leaves in Hy-S as compared with Hy-S receiving zero or one application. Both two and three metalaxyl applications on Hy-R significantly reduced percent infected leaves as compared with Hy-R receiving zero or one application.

Disease progress curves for the 1986 study were developed from weekly samplings (Fig. 3) and fitted to the logistic, monomolecular, and Gompertz models (2). The Gompertz model was empirically judged to have the best overall fit among first growth data (Table 1) and the monomolecular model, the poorest fit. No model was judged to fit well with regrowth data. The linearized form of the Gompertz model is: $-\ln[-\ln(y)] = -\ln[-\ln(y_0)] + r_G t$, where y is proportion of leaves infected, y_0 is the intercept, and r_G is the slope or rate parameter.

One or two applications applied to susceptible Hy-S, with intercept estimates, $\hat{y}_0$, of −6.62 and −6.19, respectively, (Table 1) delayed initial infection for at least 2 wk (Fig. 3) when compared with zero applications with $\hat{y}_0$ of −5.43 (Table 1). On the resistant Hy-R, one or two applications resulted in a 2-wk delay, with $\hat{y}_0$ of −5.25 and −5.31, respectively, compared with zero application with $\hat{y}_0$ of −4.69.

Rate of disease progress, $\hat{r}_G$, was less for the resistant than for the susceptible cultivar, but similar within cultivars, regardless of number of applications (Table 1).

Responses at first harvest among cultivars and fungicide applications were similar for percent leaves infected (whole plant samples) and percent leaf area with lesions (single leaf samples) (Table 2). Regrowth was damaged by hail, and estimates of percent leaf area with lesions were not possible.

DISCUSSION

In this study, partial resistance accounted for a greater reduction in white rust disease than did soil application of metalaxyl. Disease incidence in the partially resistant cultivar without metalaxyl was lower at every harvest than in the susceptible cultivar with one, two, or three applications of metalaxyl. A similar response has been reported for Phytophthora root and stalk rot of soybean (1).

Others have previously reported that metalaxyl rates needed to achieve a certain level of control for lettuce downy mildew are less on cultivars with partial resistance (6,20). The effects of both protectant fungicides and metalaxyl were additive when combined with partial resistance to potato late blight (10,14).

In our study, a decreased incidence of white rust with each subsequent metalaxyl application to the resistant cultivar was significant only under the epidemic conditions encountered at second harvest in season 2. Under the less severe conditions at first harvest and at second harvest of season 1, metalaxyl applications did not significantly reduce disease incidence in Hy-R. On the susceptible cultivar, only the first metalaxyl treatment provided a significant disease reduction at first harvest and at second harvest of season 1. Subsequent applications did not further reduce disease incidence. None of the metalaxyl applications on Hy-S or Hy-R provided suitable spinach for processing at second harvest of season 2. It is doubtful if the additional disease control achieved from two or more applications is economically desirable for growers, regardless of the level of partial resistance present in the cultivar planted. This is especially true with processing

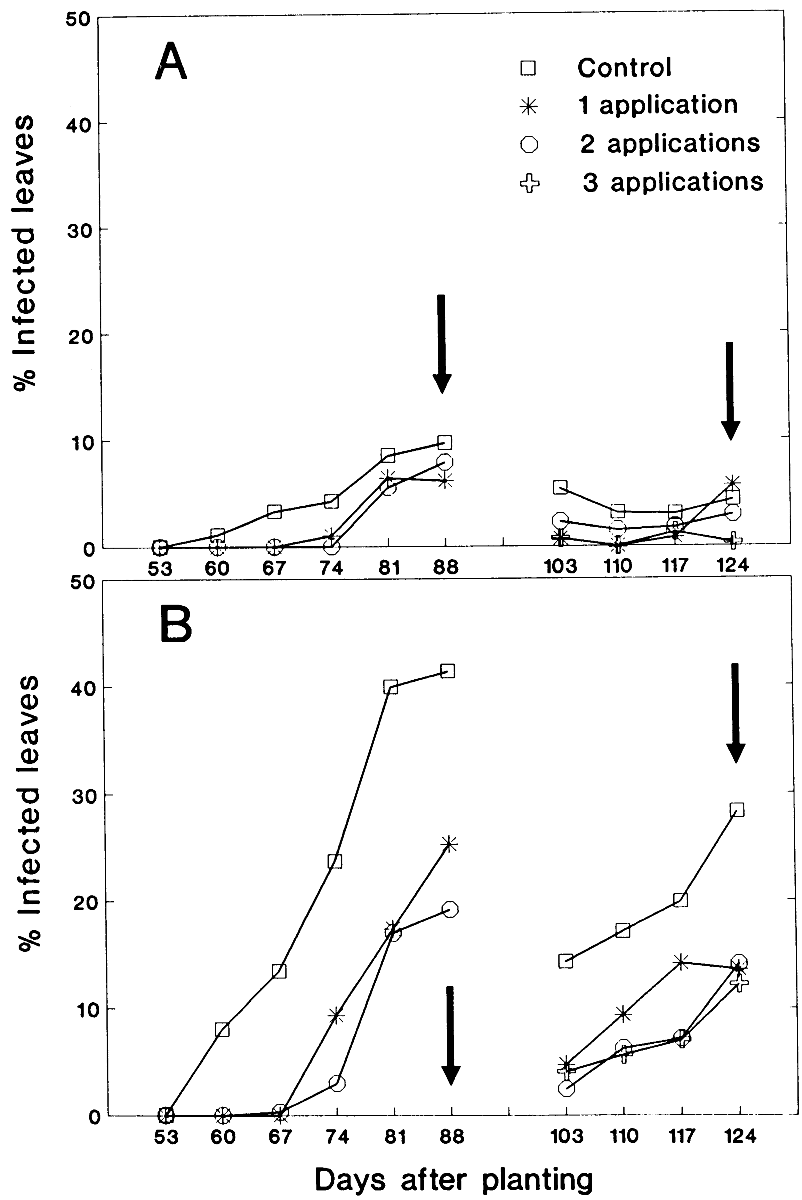

Fig. 3. White rust disease progression for **(A)** partially resistant Hy-R and **(B)** susceptible Hy-S spinach cultivars as influenced by multiple metalaxyl applications during season 1. Arrows indicate harvest dates.

Table 1. Summary of statistics from 1986 white rust disease progress curves fitted to the Gompertz model in first growth for spinach cultivars and metalaxyl applications

Cultivar	Number of metalaxyl applications	R^2	Intercept ($\hat{y}_0$)	SD of intercept	Slope ($\hat{r}_G$)	SD of slope
Hy-R	0	69.6	−4.69	0.46	0.046	0.006
	1	76.0	−5.25	0.41	0.048	0.006
	2	69.5	−5.31	0.48	0.047	0.007
Hy-S	0	80.5	−5.43	0.50	0.067	0.007
	1	82.3	−6.62	0.51	0.072	0.007
	2	79.1	−6.19	0.51	0.065	0.007

Table 2. Influence of multiple metalaxyl soil applications and partial resistance on percent leaf area with white rust lesions at first harvest of 1986 season

Number of metalaxyl applications	Spinach cultivar		Application mean
	Hy-S	Hy-R	
0	7.1	0.9	4.0
1	3.0	0.4	1.7
2	2.2	0.2	1.2
	$LSD_{0.05} = 1.4$[a]		$LSD_{0.05} = 1.0$[b]
Cultivar mean	3.6	0.4	$LSD_{0.05} = 1.4$[c]

[a]To compare number of applications (subplot) on the same cultivar (main plot).
[b]To compare number of applications.
[c]To compare cultivars.

spinach, in which low levels of white rust can be tolerated in the harvested product.

Delayed initiation of white rust epidemics is the major benefit from metalaxyl soil applications, as seen in slope and intercept estimates of linearized disease progress curves. Initial infection from *A. occidentalis* occurs from oospores formed on a previous spinach crop (18). Rapid secondary spread of the pathogen occurs by means of airborne sporangia (16). Thus, primary infection from localized oospores can be delayed and/or reduced with an in-furrow application of metalaxyl at planting. If primary infection in a given field is eliminated, reduced, and/or delayed, then harvest can often occur before spread from nearby fields reduces quality to an unusable level.

Applications made after planting but before first harvest were ineffective in controlling white rust in the regrowth crop. This response is speculated to be the result of increased density of sporangia late in the season and/or dilution of the same quantity of metalaxyl required to protect a much larger plant than the at-planting application. This may explain why percent leaf area with lesions was not significantly affected by subsequent metalaxyl treatments. Leaf area with lesions was influenced more by partial resistance than by metalaxyl. This agrees with Williams et al (19), who reported that the area of sporulating annulus of late blight of potatoes was smaller in resistant cultivars. Additional research is suggested to determine if increasing the rate of metalaxyl in subsequent applications to compensate for increasing growth can offer significant reductions in white rust incidence.

Although at-planting application of metalaxyl delayed initial white rust symptoms by 2–3 wk, this study provides an economic argument against second and third metalaxyl applications on both susceptible and partially resistant cultivars. This small plot study favored greater than usual disease development because of high oospore densities in soil and positive interplot interference (cryptic error) (2) from adjacent plots of highly susceptible cultivars producing abundant airborne sporangia. White rust in commercial fields of resistant spinach cultivars receiving metalaxyl only at planting during both seasons was considerably later in initial onset and lower in final disease severity (T. E. Kunkel, *unpublished*). This was attributed to lower oospore densities in soil because of crop rotation and to low sporangia numbers in the air because of physical separation from susceptible cultivars.

The high disease incidence at the second harvest of season 2 demonstrates the destructive potential of white rust in spinach. Data collected at the end of season 2 after flower stalks were initiated agree with a previous report of rapid disease development and oospore formation at this growth stage (16). The different final harvest dates for the two seasons apparently contributed to inconsistent ranking among fungicide applications.

The agreement between statistical analyses of data from two sampling techniques indicated that the less destructive single leaf sampling can be used to avoid stand loss from repeated whole plant sampling.

Early destruction of plants in abandoned spinach fields is necessary to prevent recurring disease problems in subsequent years caused by deposition of high numbers of oospores in the soil. We feel that genetic, cultural, and chemical control methods should be integrated in order to reduce the areawide potential for white rust, a compound-interest disease. In addition to short-term benefits, reducing the oospore production in infected lower leaves that are not harvested will benefit future crops of spinach in the Winter Garden, where limited area with irrigation equipment forces growers to use fairly short rotations.

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