Metalaxyl Controls Downy Mildew and Supplements Horizontal Resistance to *Bremia lactucae* in Lettuce Grown on Organic Soil in New York

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ABSTRACT

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In field trials during 1979 to 1981, metalaxyl (Ridomil 2EC and 5G) controlled downy mildew of lettuce caused by *Bremia lactucae* on lettuce grown on organic soil in New York state. In 1979, four weekly sprays of metalaxyl (Ridomil 2EC) at three rates from 0.14 to 0.56 kg a.i./ha or a single spray of metalaxyl (Ridomil 2EC) at 1.12 kg a.i./ha were more effective in controlling downy mildew than four weekly sprays of mancozeb at 1.79 kg a.i./ha. In 1980, metalaxyl (Ridomil 5G) from 0.5 to 1.5 kg a.i./ha placed in the seed furrow at planting reduced the incidence of downy mildew in the lettuce cultivars Ithaca, Mesa 659, and Minetto. This effect was uniform despite the various levels of horizontal resistance in the three lettuce cultivars. No interaction between cultivars of lettuce and metalaxyl was detected. In 1981, there was an interaction between metalaxyl (Ridomil 5G) applied at planting at 1.5 kg a.i./ha and metalaxyl (Ridomil 2EC) applied midway through the growing season at 1.0 kg a.i./ha, although all fungicide treatments controlled downy mildew.

Additional key words: *Lactuca sativa*

Downy mildew of lettuce (*Lactuca sativa* L.) caused by *Bremia lactucae* Regel can be a serious problem on lettuce grown on organic soil in New York state in spite of repeated applications of the currently registered dithiocarbamate fungicides. Most growers have reported that these are ineffective in controlling downy mildew. Although there are race-specific resistant cultivars of lettuce, they are unsuitable for growing in New York. Furthermore, races of *B. lactucae* already exist there that are virulent on most if not all of these cultivars (13). Another possible control measure is the use of fungicides specific for oomycetes. Paulus et al (11), Crute (4), and Bruin and Edgington (3) have indicated that metalaxyl can be effective in controlling lettuce downy mildew. This work was undertaken to determine the suitability of using metalaxyl to control downy mildew of lettuce grown on organic soil in New York.

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MATERIALS AND METHODS

All trials were conducted during 1979 and 1981 in commercial lettuce fields (organic soil) in Oswego County, NY. In this region, lettuce fields are usually double-cropped each season and all trials were done during the second planting. This allowed selection of sites where lettuce downy mildew had been observed on the first planting and ensured that a supply of natural inoculum of *B. lactucae* would be present. Routine applications of insecticides and herbicides along with thinning and weeding of the lettuce were performed by the grower cooperators. Because of the varying amounts of mildew that developed and because the techniques for quantifying the amount of disease present were being refined continually, the method of disease assessment differed with each trial.

1979 Trial. The trial was a randomized complete block design with four replicates. The fungicides were applied as foliar sprays to lettuce (cultivar Ithaca) seeded by the grower cooperator on 21 July (Table 1). Fungicide application began on 22 August, shortly after the lettuce had been thinned. Four weekly sprays (22 and 29 August and 5 and 12 September) of metalaxyl (Ridomil 2EC) at rates of 0.14, 0.28, and 0.56 kg a.i./ha were applied using a CO_2 pressurized sprayer at 1.72 kPa. The first two applications were made with drop nozzles to ensure complete coverage of the plants, but ordinary overhead nozzles were used for the last two sprays because the frame leaves had filled the spaces between the plants. Four weekly sprays of both mancozeb (Manzate 200 80WP) at 0.79 kg a.i./ha and a water control were also applied in a similar manner. An additional fungicide treatment consisting of a single application of metalaxyl (Ridomil 2EC) at 1.12 kg a.i./ha was applied using the sprayer with drop nozzles on 22 August to test the efficacy of a single high-rate application. Treatment plots consisted of single rows 7.7 m long and 0.40 m wide. Fungicide sprays were applied in water at a rate of 935 L/ha.

The trial was rated for mildew three times (29 August, and 7 and 19 September) but only data for the last rating are presented. Ten plants from each treatment plot were classified into one of five disease classes (0 = disease-free and 4 = heavily infected). Classes 0–2 were considered marketable and classes 3 and 4 were considered not marketable. The proportion of marketable plants was computed for each of the treatment plots and an analysis of variance was

Table 1. Fungicide treatments and resulting means of percent marketable plants from the 1979 trial

Treatment (a.i./ha)[a]	Percent marketable heads[b]
Metalaxyl (Ridomil 2EC) 1.12 kg[c]	92.5
Metalaxyl (Ridomil 2EC) 0.56 kg	100.0
Metalaxyl (Ridomil 2EC) 0.28 kg	100.0
Metalaxyl (Ridomil 2EC) 0.14 kg	90.0
Mancozeb (Manzate 200 80WP) 1.79 kg	67.5
Control	27.5

[a] All treatments included Triton B-1956 at the rate of 438 ml/ha applied in 935 L water/ha. All treatments applied weekly from 22 August to 12 September except as noted. Refer to text for additional details.

[b] Overall "F" value for treatments equals 7 (significant at $P = 0.01$).

[c] Sprayed only on 22 August.

performed on these data. The treatment sum of squares was then divided into single degree of freedom contrasts (Table 2) to determine the source of variation among the treatments.

1980 Trial. Because only low levels of metalaxyl were required in 1979 for downy mildew control and other formulations of metalaxyl had become available, we decided to use a different approach in 1980. In Canada, Bruin and Edgington (3) had used granular metalaxyl applied in the seed furrow at planting for direct-seeded lettuce outdoors, and in England, Crute (4) applied metalaxyl to blocking compost for transplant lettuce, and both reported excellent control of the disease. Furthermore, varietal differences among lettuce cultivars in their susceptibility to downy mildew were suspected, so we decided to investigate the possibility of an interaction between amount of metalaxyl applied at planting and different cultivars of lettuce. With these goals in mind, the trial in 1980 was planned as a factorial experiment. Three cultivars of lettuce (Ithaca, Minetto, and Mesa 659) were used as one factor and three levels of metalaxyl at 0.5, 1.0, and 1.5 kg a.i./ha along with an untreated check were used as the second factor, resulting in 12 treatments. Each treatment was replicated four times in a completely randomized design. A mixture of lettuce seed and the appropriate amount of Ridomil 5G was placed in seed furrows on single-ridge beds on 17 July using a Planet Junior cone seeder. The plots consisted of rows 12 m long and each 0.40 m wide.

The trial was rated for mildew on 11 September immediately before harvest. Total numbers of plants and total numbers of plants showing any symptoms of mildew were recorded for each treatment plot (replicate). In addition, five adjacent typical plants were harvested from each treatment plot and the circumferences of each of the five heads and the total weight of the five heads recorded. Multiple-regression analysis using a model sequence was used to analyze the data. Each of the three measured variables (incidence of disease, average head weight per plot, and average head circumference per plot) was used as the y variable in the regressions; the x variable was the level of metalaxyl from 0.0 to 1.5 kg a.i./ha (Fig. 1).

1981 Trial. The 1980 trial indicated that good control was possible with a single application of metalaxyl, but the effect of the fungicide applied at planting did not extend beyond about 60 days. Thus, it was felt that even better control might be possible by supplementing the at-planting treatment with an additional midseason treatment of metalaxyl. Therefore, the fungicide trial in 1981 was planned to address the possibility of an interaction between the application of granules at planting and the application of a spray or drench midway through the season. A factorial plan was used involving application of Ridomil 5G at 1.5 kg a.i./ha at planting in the seed furrow as one factor and application of a foliar spray or soil drench of Ridomil 2EC at 1.0 kg a.i./ha midway through the growing season as the second factor (Table 3). Lettuce seed (cultivar Ithaca) mixed with Ridomil 5G for treatments 2, 4, and 6 was placed in seed furrows in single-ridge beds on 14 July using a Planet Junior cone seeder. Each treatment was replicated four times in a randomized complete block design. The plots consisted of rows 6.1 m long and 0.40 m wide.

On 19 August, a midseason application of metalaxyl was made to treatments 3–6. For treatments 3 and 4, a soil drench consisting of Ridomil 2EC at 1.0 kg a.i./ha in water at 1,000 L/ha was applied to the plots. For treatments 5 and 6, the plants were sprayed with Ridomil 2EC at 1.0 kg a.i./ha in water at 1,000 L/ha with a CO_2 pressurized sprayer at 1.72 kPa equipped with two drop nozzles.

Table 2. Values of orthogonal contrasts of treatment means (percent marketable plants) and their "t" values (value divided by its standard error) from the 1979 trial

Contrast	Value (%)	"t" Value
Avg. of all fungicides minus water control	62.5	5.37[a]
Avg. of all metalaxyl minus zinc ion maneb	28.12	2.37[b]
Avg. of weekly sprays of metalaxyl minus single spray	4.17	0.34
Differences among weekly sprays of metalaxyl[c]	...	...

[a]Significant at $P = 0.01$.
[b]Significant at $P = 0.05$.
[c]The three weekly sprays were not significantly different from each other. "F" value was 0.295.

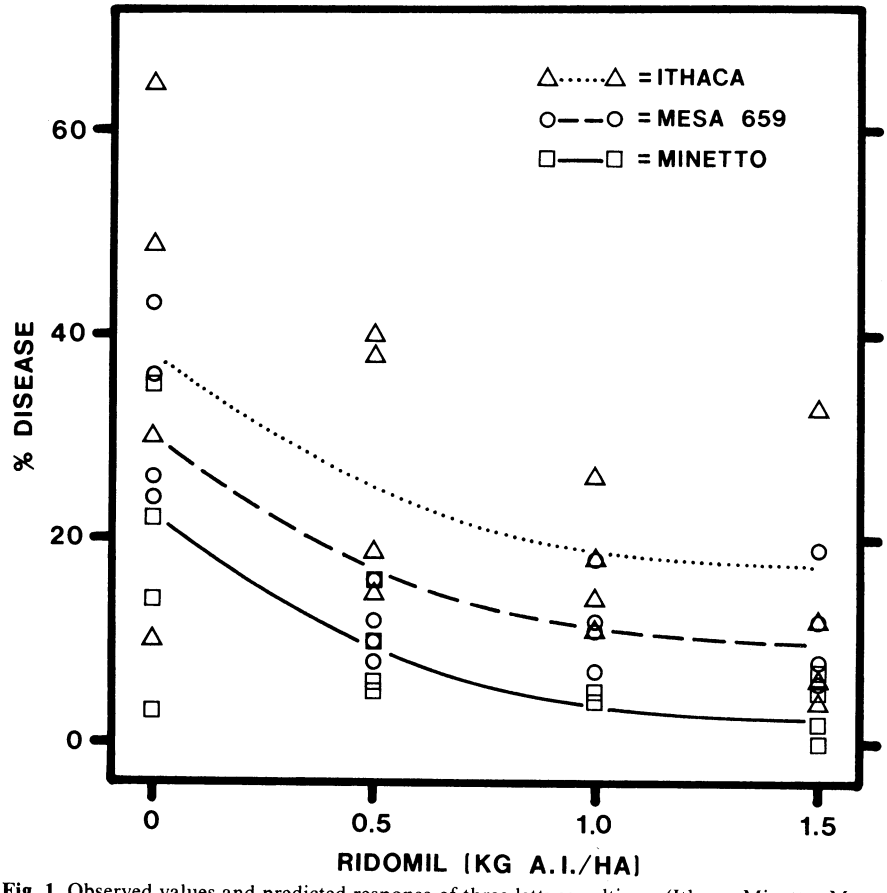

Fig. 1. Observed values and predicted response of three lettuce cultivars (Ithaca, Minetto, Mesa 659) when seeded with varying levels (0.0, 0.5, 1.0, and 1.5 kg a.i./ha) of metalaxyl (Ridomil 5G). Ithaca intercept = 37.75, Mesa 659 intercept = 29.81, Minetto intercept = 22.06, common slope = −31.51 ("t" = −3.60), and common quadratic = 12.08 ("t" = 2.16).

Table 3. Fungicide treatments with metalaxyl and resulting means of downy mildew incidence in 1981

Treatment	Percent mildew[a]
No fungicide	82.0
At planting only[b]	7.5
As drench only[c]	37.3
At planting and as drench[b,c]	0.0
As foliar spray only[d]	2.2
At planting and as foliar spray[b,d]	4.8

[a]Overall "F" value equals 35.7 (significant at $P = 0.001$).
[b]Metalaxyl (Ridomil 5G) applied at planting directly in the seed furrow (1.5 kg a.i./ha).
[c]Metalaxyl (Ridomil 2EC) applied as a drench (1.0 kg a.i./ha) in water (1,000 L/ha).
[d]Metalaxyl (Ridomil 2EC) applied as a foliar spray (1.0 kg a.i./ha) in water (1,000 L/ha).

The trial was rated for mildew on 16 September. Because of heavy rainfall and poor drainage, the lettuce stand was very uneven, making more sophisticated methods of measuring disease such as leaf area assessments or head weights or circumferences impractical. The incidence of mildew for each plot was determined on all plants within each plot and an analysis of variance was performed on these data. The treatment sum of squares then was divided into single degree of freedom contrasts to determine the source of variation among the treatments.

RESULTS

1979 Trial. Metalaxyl provided excellent control of downy mildew, whereas mancozeb provided moderate control when compared with the untreated check (Table 1). There were differences among the means of percent marketable heads in each treatment as indicated by the large "F" value (7.02). An attempt was made to locate these differences in percent marketable heads by partitioning the treatment sum of squares with four orthogonal contrasts (Table 2).

1980 Trial. Incidence of mildew on the three different cultivars of lettuce decreased as the amount of metalaxyl was increased. The rate of this decrease in the incidence of downy mildew was the same for each cultivar, but each cultivar had its own mean response (Fig. 1). Ithaca was the most susceptible to mildew, Mesa 659 less susceptible, and Minetto the least susceptible. Less mildew occurred at higher levels of metalaxyl, as indicated by the negative slope of the response line, a significantly ($P = 0.05$) nonzero response. At the higher levels of metalaxyl, the ability of the fungicide to reduce the incidence of downy mildew decreased, as indicated by the curve in the response lines. This curvature (the quadratic component of the line) also was significantly ($P = 0.05$) nonzero. In regressions of either head weight or head circumference, no effect of metalaxyl was evident. There was no trend for any change in head size or weight as the amount of metalaxyl was increased.

1981 Trial. Application of metalaxyl in each of five treatments substantially reduced the incidence of downy mildew (Table 3). The levels of downy mildew resulting from the different treatments were not the same, as indicated by the large "F" value (35.7). Because of these differences, an attempt was made to identify the nature of the differences by testing a number of contrasts among the treatment means.

In this analysis, the possibilities of an interaction between the mode and the timing of the metalaxyl applications were the first two contrasts examined (Table 4). Both interactions were significant so neither the main effects nor the interaction contrasts were analyzed further. Instead, the effect of the application of the fungicide midway through the season and a comparison of the two types of metalaxyl application midway through the season were made for the treated-at-planting and the not-treated-at-planting groups. This resulted in the five orthogonal contrasts presented in Table 4.

DISCUSSION

During the 3 yr of testing from 1979 to 1981, metalaxyl was very effective in controlling lettuce downy mildew in Oswego County, NY. Excellent control was obtained with foliar sprays applied in four weekly applications, with foliar sprays applied once with soil drenches or with granules placed in the seed furrow at planting. The experiments indicate that very little metalaxyl is required to control downy mildew and that only one or two applications of fungicide are required for disease control.

In 1979, application of both metalaxyl and mancozeb increased the number of marketable heads of lettuce, but there were differences between these two fungicides because metalaxyl was much more effective than mancozeb. There was no significant difference between a single application of metalaxyl at 1.12 kg a.i./ha and the four weekly sprays at rates from 0.14 to 0.55 kg a.i./ha. Furthermore, there were no significant differences among these three different rates when applied as four weekly sprays. Under 1979 growing conditions, metalaxyl was very effective with no need for high levels or frequent applications to control downy mildew. Similarly, Paulus et al (11) found that two sprays of metalaxyl at 0.28 kg a.i./ha gave excellent control of downy mildew in California, and Crute (4) and Bruin and Edgington (3) found that metalaxyl applied in a number of modes was effective in controlling downy mildew.

The lack of an interaction between the three cultivars and level of metalaxyl in the 1980 trial was not unexpected. In previous studies, Mesa 659 was less susceptible to downy mildew than Ithaca. The lower incidence of downy mildew in Minetto, however, was rather unexpected because both Ithaca and Minetto were much more similar to each other than they were to Mesa 659. The lack of an interaction between horizontal resistance in the cultivars of lettuce and the response to different levels of metalaxyl indicates that these effects are additive, and the amount of fungicide needed to achieve a certain level of control depends on the relative horizontal resistance of the cultivar planted. Thus, more resistant cultivars require less fungicide. This adjustment of fungicide application rates due to horizontal resistance has also been calculated for potatoes and late blight (6).

If a phytotoxic effect caused by metalaxyl had been present in the 1980 trial, it would have tended to decrease the size of the lettuce heads. Conversely, if disease pressure had been high, controlling downy mildew would have increased the size of the heads. Because no increase or decrease in head size or weight was noted, either the levels of metalaxyl used in this experiment were not phytotoxic or if they were, they were offset by the disease control contributed by the fungicide.

The significant interactions from the 1981 trial indicate that applying metalaxyl either at planting as a granule or midseason as a spray or drench was all that was needed to control downy mildew. If metalaxyl was applied as a granule at planting, no decrease in disease incidence could be attributed to the midseason application of metalaxyl. In the absence of metalaxyl applied as a granule, a midseason application of metalaxyl (either a spray or a drench) decreased the incidence of downy mildew. Comparison of a midseason spray application with a midseason drench application (in the absence of metalaxyl applied at planting) indicated that the spray is significantly better at reducing the incidence of downy mildew compared with the drench.

A midseason application of fungicide

Table 4. Values of contrasts of treatment means (percent infected plants) and their "t" values (value divided by its standard error) from the trial in 1981

Contrast	Value (%)	"t" Value
Interaction contrasts		
Interaction between granules and midseason application	57.0	6.10[a]
Interaction between granules and mode of midseason application	39.5	3.66[a]
Orthogonal contrasts		
Reduction in mildew due to a midseason application in presence of granular fungicide	5.25	0.79
Reduction in mildew due to spray application compared with drench application, both in presence of granular fungicide	−4.50[b]	−0.59[b]
Reduction in mildew due to midseason application with no fungicide at planting	62.21	9.41[c]
Reduction in mildew due to spray application compared with drench application with no fungicide at planting	34.90	4.58[c]
Overall reduction in mildew due to application of granules	36.41	8.28[c]

[a] Significant at $P = 0.01$.
[b] This value is negative because of higher incidence of mildew in the spray treatment than in the drench treatment.
[c] Significant at $P = 0.001$.

was not needed during 1981; this may have been due to the peculiar weather during the growing season. In the trial during 1980, control of downy mildew by a single application of metalaxyl at planting was not as complete as during 1981. Further testing is necessary to determine the amount and timing of the midseason application of metalaxyl. Although conditions surrounding the trial during 1981 were far from ideal and generated data that might be viewed as unrealistic when compared with a normal growing season, it was evident that metalaxyl was effective in preventing lettuce downy mildew even under these adverse conditions.

Recent evidence from both England and the Netherlands (1,8,10) indicates that oospores of *B. lactucae* can germinate and infect lettuce seedlings. Both mating types of *B. lactucae* and oospores in field-collected material have been found in Oswego County (*unpublished*). Thus, the granular in-furrow application of metalaxyl should be effective in protecting young plants and germinating seeds from oospore infections.

Control of *B. lactucae* on lettuce in New York is possible by using one or two applications of metalaxyl at relatively low rates. However, metalaxyl-resistant strains of *B. lactucae* may already exist but have not been detected. Metalaxyl-resistant strains of other downy mildew fungi have already been reported (2,5,7,9,12). The *B. lactucae* population in New York may be diverse with respect to metalaxyl resistance, but these resistant strains may be uncovered only after metalaxyl has been in use for some time. Therefore, mixtures of metalaxyl with other fungicides or alternating applications of metalaxyl with other fungicides may be necessary to prevent selection for metalaxyl-resistant strains of *B. lactucae*.

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