# Sterol-Inhibiting Fungicides for Control of Sugar Beet Powdery Mildew, Methods and Rates of Application and Evidence of Growth Regulation

F. J. HILLS and G. A. NIKOLICH, Department of Agronomy, and L. D. LEACH, Department of Plant Pathology, University of California, Davis 95616

**ABSTRACT**

Hills, F. J., Nikolich, G. A., and Leach, L. D. 1985. Sterol-inhibiting fungicides for control of sugar beet powdery mildew, methods and rates of application and evidence of growth regulation. Plant Disease 69:257-261.

Trials were conducted to evaluate various rates and methods of applying three sterol-inhibiting fungicides: triadimefon, nuarimol, and propiconazol. Crown sprays, and especially crown-applied granules, generally provided superior season-long control compared with broadcast applications. Rate of application of crown-applied materials was related negatively to disease severity, with 0.56 kg a.i./ha providing consistently effective long-term disease suppression. Results suggest that a slow-release granular formulation applied to crowns may improve the duration of disease control. Triadimefon or nuarimol granules applied at 1.12 kg a.i./ha gave significantly higher yields than did biweekly sulfur treatments even though disease levels were comparable. This indicates that these fungicides may have a growth-promoting effect.

Additional key words: *Erysiphe betae, E. polygoni*

Powdery mildew of sugar beet, caused by *Erysiphe polygoni* DC. (*E. betae* (Vanha) Weltzien), has been of concern to California growers since the first epiphytotic in 1974 (7,11). Since that time, the principal method for control has been two or three applications of dusting sulfur (45 kg S/ha per application) (6). From 1974 to 1979, a number of studies to evaluate various alternatives to sulfur for control of this disease indicated that a group of systemic fungicides noted for their ability to inhibit sterol biosynthesis in fungi had potential for effective control of powdery mildew of sugar beet (4,10,12). Frate et al (4) showed that applications of a granular formulation of sterol inhibitors to crowns of sugar beet were more effective than broadcast sprays. In several trials, granular applications have resulted in root yield increases that were greater than might be expected by disease control alone (4,5). This paper presents the results of continuing studies to evaluate various formulations, rates, and application techniques for three sterol inhibitors. In addition, two were evaluated for their potential growth-promoting effects.

## MATERIALS AND METHODS

The three sterol-inhibiting fungicides evaluated were triadimefon (Bayleton), nuarimol (Trimidal), and propiconazol (Tilt). Triadimefon was formulated as 50% a.i. wettable powder (WP) or 2.5 or 5% granules (G), nuarimol was formulated as a 90-g a.i./L emulsifiable concentrate (EC) or 1 or 5% a.i. G, and propiconazol was formulated as a 432-g a.i./L EC or 2.5% a.i. G.

Fungicide sprays were applied either broadcast with a flat 80-degree nozzle oriented perpendicular to the plant row or to plant crowns with a flat fan 25-degree nozzle adjusted parallel to and centered over the plant row. All applications were made with a $CO_2$-pressurized backpack sprayer. In the 1980 trial, granules were applied at layby (just before leaves close the furrow between plant rows) with a Clampco Select-a-Dial (Clampco, Inc., Salinas, CA) set up to deliver the material to the plant crowns via flexible hoses centered over the rows. In subsequent trials, granules were delivered by hand from packets with individual contents measured to cover 3.1 m of row. The contents of an appropriate number of packets were directed over the center of each row in marked 3.1-m sections to simulate the Select-a-Dial application. Crown applications, both spray and granular, were always made at layby to simulate the timing for a latest-possible tractor-drawn ground application. Broadcast sprays were applied at the first sign of disease, often in 94 L of water per hectare to simulate the volume used for aerial

**Table 1.** Comparison of three methods of applying triadimefon and propiconazol at a single rate with a single application of sulfur at Davis, CA, in 1980[a]

| Treatment[b] | Application rate (kg a.i./ha) | Average mildew severity[c] | | Fresh root wt (t/ha) | Root sucrose | |
|---|---|---|---|---|---|---|
| | | Rating | % MLAD | | Conc. (%) | Yield (t/ha) |
| Check | ... | 1.89 | 31 | 75.2 | 13.4 | 10.1 |
| Sulfur | 22.4 | 1.47 | 20 | 78.6 | 12.6 | 9.9 |
| Triadimefon | | | | | | |
| Broadcast | 0.56 | 1.09 | 11 | 74.7 | 13.1 | 9.9 |
| Crown spray | 0.56 | 0.58 | 3 | 86.1 | 12.6 | 10.9 |
| Granules | 0.56 | 0.25 | 0.6 | 88.7 | 13.3 | 11.8 |
| Propiconazol | | | | | | |
| Broadcast | 0.56 | 0.36 | 1 | 83.3 | 13.1 | 11.0 |
| Crown spray | 0.56 | 0.64 | 4 | 84.6 | 13.7 | 11.6 |
| Granules | 0.56 | 1.34 | 17 | 77.8 | 13.5 | 10.5 |
| *F* ratio[d] | | | | | | |
| All treatments | | 24.7*** | ... | 4.4** | 2.4* | 3.4** |
| Among systemics | | 1.4 | ... | 5.3 | 1.4 | 3.0* |
| Fungicide (F) | | 2.5 | ... | 0.5 | 3.0 | 0.3 |
| Method (M) | | 1.6 | ... | 4.0* | 0.3 | 2.4 |
| F × M | | 33.43*** | ... | 9.0** | 1.7 | 4.8* |
| LSD (0.05) | | 0.33 | ... | 6.6 | 0.9 | 1.2 |
| C.V. (%) | | 21.5 | ... | 5.7 | 4.8 | 7.9 |

[a] US H11 was seeded on 22 April, layby was 56 days after planting (DAP), the first sign of disease was 84 DAP, and harvest was 162 DAP.

[b] All fungicides were applied at layby. Broadcast and crown sprays (triadimefon, 50% WP, and propiconazol, 432 g a.i./L EC) were applied in 234 L of water per hectare. Triadimefon granules were 5% a.i.; propiconazol granules were 2.5% a.i. Sulfur represents the average of three treatments: two broadcast in 234 and 468 L of water per hectare and the third applied with drop nozzles in 468 L of water per hectare. All were applied once and there were no significant differences among them.

[c] Average biweekly mildew ratings weighted by weeks from observation to 1 October. % MLAD = percent mature leaf area diseased.

[d] Statistical significance indicated by * = $P = 0.05$, ** = $P = 0.01$, and *** = $P = 0.001$.

Accepted for publication 17 September 1984.

The publication costs of this article were defrayed in part by page charge payment. This article must therefore be hereby marked "*advertisement*" in accordance with 18 U.S.C. § 1734 solely to indicate this fact.

©1985 The American Phytopathological Society

application. All sulfur treatments were applied as broadcast sprays (flowable formulation of 720 g of S/L). Experimental designs were randomized complete blocks with four replicates in 1980 and 1982, a split plot with three replicates in 1981, and a 6 × 6 latin square in 1983.

Sugar beet seeds were planted in raised planting beds spaced 76 cm apart and furrow-irrigated for emergence. After stand establishment, furrow irrigations were continued on a biweekly schedule. Plots were four rows wide, and 15.2 or 18.3 m of the center two rows were harvested. Two samples (eight to 10 beet roots) were taken from each plot and evaluated for sucrose and tare at a nearby commercial sugar beet tare laboratory.

Disease was a result of natural infection in all trials. We estimated leaf area infected by powdery mildew with biweekly visual examinations of 25 fully mature leaves per plot using a pretransformed scale of 0–5 (5). Percent mature leaf area diseased (% MLAD) is estimated by the following transformation: % MLAD = 100 $\{\text{sine}\,[18° \text{(rating)}]\}^2$, where 18° is one-fifth of 90°, the range of angular transformation of percentages to degrees (9).

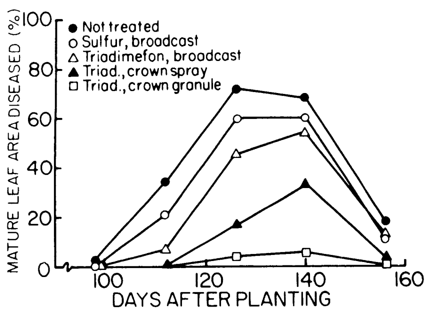


**Fig. 1.** Effect of method of application of triadimefon (0.56 kg a.i./ha) and sulfur (22.4 kg/ha) on disease suppression at Davis, CA, in 1980. All applications were at layby, 56 days after planting (DAP). The first sign of disease was 84 DAP.

## RESULTS AND DISCUSSION

**Disease control, 1980.** Table 1 shows the results of a trial that compared three methods of applying triadimefon and propiconazol with a single application of sulfur (22.4 kg a.i./ha).

Powdery mildew was first detected on 15 July, 84 days after planting (DAP) and 28 days after the layby fungicide applications. It is apparent from Figure 1 that a single sulfur spray at layby was inadequate for suppression of powdery mildew—a result also supported by the yield data of Table 1. When disease progress was compared for the various methods of applying triadimefon (Fig. 1), both types of crown applications (spray and granular) were superior to the broadcast spray. The differences, though quite small for the month following the first sign of disease, increased markedly after 112 DAP. Crown-applied triadimefon granules significantly suppressed disease compared with a crown spray (Table 1). On the other hand, propiconazol granules produced the highest average mildew rating for that material (Table 1). Both triadimefon and propiconazol provided significant increases in both fresh root weight and gross sucrose yield compared with check plots. Triadimefon was effective when applied as granules and propiconazol when applied as a crown or broadcast spray. There were no apparent reasons why propiconazol performed poorly as a granular crown application, particularly when it worked well as a crown spray. This point should be investigated further.

**Disease control, 1981.** This trial was designed to compare the three systemic fungicides as crown and broadcast sprays at three rates. Main plot treatments were the six combinations of broadcast versus crown applications × three rates plus a zero rate (check) containing three identical subplots to balance the treatment design. The other main plots were split into subplots for the three fungicides.

The first sign of disease was recorded 68 DAP (6 July), 1 wk after the layby applications. Over all rates and both methods of application, propiconazol gave significantly better disease control (9% MLAD) than triadimefon (15% MLAD) and nuarimol (13% MLAD) (Table 2). On the average, crown application (8% MLAD) significantly improved disease control compared with broadcast application (14% MLAD) and there was a highly significant rate effect with 0.14, 0.28, and 0.56 kg a.i./ha, giving 24, 9, and 3% MLAD, respectively. The application rate of 0.14 kg a.i./ha provided little or no disease control. Figure 2 shows the seasonal development of powdery mildew and compares methods of application for the two higher rates averaged over all three fungicides.

In terms of root and sugar yield, there were no significant differences among the three fungicides and only a small average improvement of 4.5 and 0.8 t/ha, respectively, in treated over untreated plots. There was a significantly greater increase in root sucrose concentration

**Table 2.** Comparison of three rates and two methods of applying triadimefon, propiconazol, and nuarimol at Davis, CA, in 1981[a]

| | | | Average mildew severity[c] | | Fresh root | Root sucrose | |
|---|---|---|---|---|---|---|---|
| Application method[b] | Rate (kg a.i./ha) | Fungicide | Rating | % MLAD | wt (t/ha) | Conc. (%) | Yield (t/ha) |
| Check | ··· | None | 1.52 | 21 | 68.1 | 16.2 | 11.0 |
| Broadcast sprays | 0.14 | Triadimefon | 1.96 | 33 | 71.7 | 16.1 | 11.6 |
| | | Propiconazol | 1.77 | 28 | 71.5 | 15.7 | 11.2 |
| | | Nuarimol | 1.94 | 33 | 71.5 | 16.1 | 11.5 |
| | 0.28 | Triadimefon | 1.16 | 13 | 71.2 | 16.4 | 11.7 |
| | | Propiconazol | 0.86 | 7 | 73.7 | 17.0 | 12.5 |
| | | Nuarimol | 1.20 | 14 | 74.4 | 16.7 | 12.4 |
| | 0.56 | Triadimefon | 0.83 | 7 | 73.4 | 16.9 | 12.4 |
| | | Propiconazol | 0.34 | 1 | 73.0 | 17.0 | 12.4 |
| | | Nuarimol | 0.94 | 8 | 69.7 | 16.7 | 11.6 |
| Crown sprays | 0.14 | Triadimefon | 1.59 | 23 | 70.1 | 16.0 | 11.3 |
| | | Propiconazol | 1.20 | 14 | 72.6 | 16.4 | 11.9 |
| | | Nuarimol | 1.28 | 15 | 68.3 | 16.6 | 11.4 |
| | 0.28 | Triadimefon | 1.09 | 11 | 75.7 | 15.8 | 11.9 |
| | | Propiconazol | 0.69 | 5 | 76.8 | 16.0 | 12.3 |
| | | Nuarimol | 0.99 | 9 | 73.0 | 15.6 | 11.4 |
| | 0.56 | Triadimefon | 0.82 | 7 | 71.2 | 16.5 | 11.7 |
| | | Propiconazol | 0.44 | 2 | 72.8 | 16.8 | 12.2 |
| | | Nuarimol | 0.20 | 0.4 | 74.8 | 16.4 | 12.3 |
| C.V. (%) | | | | | | | |
| Main plot error | | | 33.2 | ··· | 7.3 | 2.6 | 6.7 |
| Subplot error | | | 21.4 | ··· | 5.5 | 2.4 | 5.4 |
| *F* ratio[d] | | | | | | | |
| Check vs. others | | | 11.0*** | ··· | 5.6* | 1.0 | 8.6* |
| Methods (M) | | | 8.7* | ··· | 0.2 | 5.5* | 0.2 |
| Rates (R) | | | 33.9*** | ··· | 1.7 | 8.5** | 3.3 |
| M × R | | | 1.3 | ··· | 0.4 | 10.7** | 0.3 |
| Fungicides (F) | | | 7.9** | ··· | 0.4 | 0.7 | 1.0 |
| F × M | | | 3.2 | ··· | 0.1 | 0.3 | 0.3 |
| F × R | | | 0.5 | ··· | 0.1 | 1.5 | 0.3 |
| F × M × R | | | 1.4 | ··· | 1.3 | 1.0 | 1.9 |

[a] US H11 was seeded on 29 April, layby was 61 days after planting (DAP), the first sign of disease was 68 DAP, and harvest was 169 DAP.

[b] Crown sprays were applied at layby in 234 L of water per hectare (triadimefon, 50% WP; propiconazol, 432 g a.i./L EC; nuarimol, 90 g a.i./L EC). Broadcast sprays were applied at the first sign of disease in 94 L of water per hectare to simulate the volume used for aerial application.

[c] Average of biweekly ratings weighted by weeks from observation to 1 October. % MLAD = percent mature leaf area diseased.

[d] Statistical significance indicated by * = $P = 0.05$, ** = 0.01, and *** = $P = 0.001$.

from the 0.14- to the 0.56-kg a.i./ha rate when the materials were broadcast (16.0–16.8%) than when they were crown-applied (16.4–16.8%). This interaction probably reflects the improvement in disease control by crown applications and the need for a higher rate of fungicide when broadcast than when crown-sprayed to achieve comparable results. Note that % MLAD, averaged over the three fungicides (Table 2), decreased from 31 to 5% for broadcast applications at 0.14–0.56 kg a.i./ha compared with from 17 to 3% for the same rates when crown-applied.

**Disease control, 1982.** In this trial (Table 3), all three sterol inhibitors were compared at two rates of application, with each material used in a manner that earlier trials had indicated might be most effective. The first sign of powdery mildew was 71 DAP (12 July), 13 days after the granules and crown sprays had been applied. As in 1981, the higher rate of application generally gave better season-long disease control. Propiconazol significantly improved disease control as a broadcast compared with a crown spray. The average rating over both rates was 0.77 for broadcast and 1.09 for crown spray, LSD (0.05) = 0.26. Nuarimol was significantly better when crown-applied than when broadcast, with average ratings of 1.05 vs. 1.32, respectively, LSD (0.05) = 0.24, but the average ratings for the crown spray and crown granular applications were about equal (1.29 vs. 1.31). Figure 3, however, shows better late-season control with granules. In this trial, triadimefon was about equally effective when applied as a crown spray or crown granular formulation.

The greatest fresh root weights were found at the rate of 0.56 kg a.i./ha for all fungicide applications with the exception of the propiconazol crown sprays. Similarly, wherever noticeable differences in gross sucrose occurred, the higher yield was associated with the higher rate. In terms of differences between materials, the best yields were in plots treated with triadimefon granules at 0.56 kg a.i./ha. In fact, that treatment produced gross sucrose yields significantly higher than all other treatments except triadimefon crown and propiconazol broadcast sprays at 0.56 kg a.i./ha.

**Suggestions for improving disease control.** The superiority of granular and crown sprays over broadcast applications implies improved uptake through crown application. This is consistent with studies conducted with cucumber (1) and grape (8), where it was found that the movement of radioactively labeled triadimefon was upward or via lateral diffusion and that downward movement was essentially lacking. Since broadcast applications show little downward movement and therefore provide little protection for young leaves, they should not be applied before the first sign of disease. Under conditions where disease does not develop rapidly, broadcast applications might be longer lasting if delayed until 25% of the mature leaf area shows signs of disease (6). The upward movement of crown-applied sterol inhibitors and the superiority of granular crown applications over crown sprays suggests that disease control might be improved by development of slow-release granules for crown application at layby.

**Evidence of growth regulation.** Three trials (Table 4) were designed to estimate the growth-regulating effects of triadimefon and other potentially useful systemic fungicides for control of powdery mildew. The general approach was to estimate effects of disease by comparing untreated plots with plots treated biweekly with sulfur, then to estimate growth stimulation by a fungicide by comparing plots treated with sulfur alone with plots treated with sulfur plus a single crown application of a systemic fungicide.

In the 1981 trial, triadimefon significantly improved root and sugar yield by 7.6 and 1.0 t/ha, respectively, over plots treated with sulfur alone, with almost complete season-long disease control for both treatments—clearly an indication of growth stimulation apart from disease control.

The 1982 trial involved all three

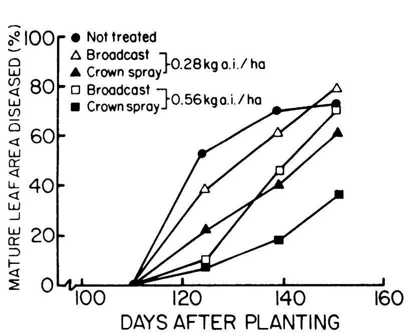


**Fig. 2.** Effect of rate and method of application on disease suppression at Davis, CA, in 1981. Data points are averages for three sterol inhibitors: triadimefon, propiconazol, and nuarimol. All applications were at layby, 61 days after planting (DAP). The first sign of disease was 68 DAP.

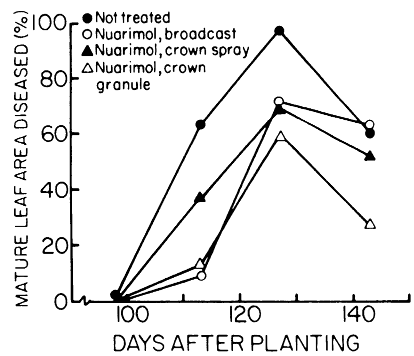


**Fig. 3.** Effect of method of application of nuarimol (0.56 kg a.i./ha) on disease suppression at Davis, CA, in 1982. All applications were at layby, 58 days after planting (DAP). The first sign of disease was 71 DAP.

**Table 3.** Comparison of two rates and three methods of applying triadimefon, propiconazol, and nuarimol at Davis, CA, in 1982[a]

| Treatment[b] | Application rate (kg a.i./ha) | Average mildew severity[c] | | Fresh root wt (t/ha) | Root sucrose | |
|---|---|---|---|---|---|---|
| | | Rating | % MLAD | | Conc. (%) | Yield (t/ha) |
| Check | ··· | 2.15 | 39 | 68.1 | 13.8 | 9.4 |
| Granules | | | | | | |
| Triadimefon | 0.28 | 1.40 | 18 | 69.0 | 14.6 | 10.1 |
| | 0.56 | 1.11 | 11 | 76.2 | 15.3 | 11.6 |
| Nuarimol | 0.28 | 1.57 | 22 | 67.9 | 14.8 | 10.0 |
| | 0.56 | 1.00 | 10 | 70.8 | 14.2 | 10.0 |
| Crown sprays | | | | | | |
| Triadimefon | 0.28 | 1.42 | 19 | 70.3 | 14.9 | 10.5 |
| | 0.56 | 0.95 | 9 | 73.0 | 15.0 | 10.9 |
| Propiconazol | 0.28 | 1.33 | 17 | 71.7 | 14.3 | 10.2 |
| | 0.56 | 0.85 | 7 | 65.6 | 15.5 | 10.2 |
| Nuarimol | 0.28 | 1.45 | 19 | 69.9 | 14.4 | 10.1 |
| | 0.56 | 1.17 | 13 | 73.0 | 14.4 | 10.5 |
| Broadcast sprays | | | | | | |
| Propiconazol | 0.28 | 0.91 | 8 | 69.4 | 14.5 | 10.0 |
| | 0.56 | 0.63 | 4 | 72.4 | 15.4 | 11.1 |
| Nuarimol | 0.28 | 1.56 | 22 | 70.8 | 13.9 | 9.8 |
| | 0.56 | 1.07 | 11 | 73.5 | 14.2 | 10.3 |
| *F* ratio[d] | | 10.7 | ··· | 2.7** | 2.6** | 2.5** |
| LSD (0.05) | | 0.37 | ··· | 4.6 | 1.0 | 1.0 |
| C.V. (%) | | 19.9 | ··· | 4.6 | 4.6 | 7.1 |

[a] US H11 was seeded on 3 May, layby was 58 days after planting (DAP), the first sign of disease was 71 DAP, and harvest was 189 DAP.

[b] Granules were applied at layby (triadimefon, 2.5% G; nuarimol, 1% G). Crown sprays were also applied at layby in 234 L of water per hectare (triadimefon, 50% WP; propiconazol, 432 g a.i./L EC; nuarimol, 90 g a.i./L EC). Broadcast sprays were applied at the first sign of disease in 94 L of water per hectare to simulate the volume used for aerial application.

[c] Average of biweekly mildew ratings weighted by weeks from observation to 1 October. % MLAD = percent mature leaf area diseased.

[d] Statistical significance indicated by ** = $P = 0.01$.

systemic fungicides. Triadimefon and nuarimol were applied both as granules and crown sprays. Because of the previous lack of disease control by granular propiconazol (Table 1), this material was only used as a crown spray. In this trial, disease severities were kept very low by all fungicide treatments, but none of the systemic materials showed a significant stimulatory yield response over sulfur alone. The "among triadimefon and nuarimol treatments" of Table 4 are a 2 × 2 factorial set: two systemics × two methods of application. There were no interactions between triadimefon and nuarimol in terms of method of application for any of the variables measured. In general, the two materials were not significantly different, but overall, crown-applied granules were significantly superior to crown-applied sprays, with the granules giving an average improvement of 4.9 [=(72.6 + 75.6 − 71.0 − 67.4)/2] and 0.9 [=(11.1 + 11.5 − 10.7 − 10.1)/2] t/ha, respectively, for root and sugar yield, with almost complete disease control for all four treatments. These effects imply a slight phytotoxic effect or a reduced stimulatory effect by a crown spray compared with a granular application. Crown sprays of propiconazol were not significantly different from crown sprays of triadimefon or nuarimol.

**Table 4.** Effect of layby crown-applied systemic fungicides and biweekly broadcast sulfur sprays on disease suppression and root and sugar yield

| Treatment[a] | Average mildew severity[b] Rating | % MLAD | Fresh root wt (t/ha) | Root sucrose Conc. (%) | Root sucrose Yield (t/ha) |
|---|---|---|---|---|---|
| | 1981[c] | | | | |
| Check | 1.62 | 24.0 | 67.8 | 15.3 | 10.5 |
| Sulfur | 0.18 | 0.3 | 72.9 | 16.0 | 11.7 |
| Triadimefon + sulfur | 0.0 | 0.0 | 80.5 | 15.8 | 12.7 |
| *F* ratio[d] | 11.0** | ··· | 7.7* | 1.4 | 4.3** |
| LSD (0.05) | 0.43 | ··· | 6.8 | NS | 1.0 |
| C.V. (%) | 37.5 | ··· | 6.1 | 3.3 | 5.9 |
| | 1982[c] | | | | |
| Check | 2.17 | 37.0 | 67.6 | 14.5 | 9.8 |
| Sulfur | 0.54 | 3.0 | 73.9 | 15.2 | 11.2 |
| Triadimefon G + sulfur | 0.08 | 0.1 | 72.6 | 15.3 | 11.1 |
| Triadimefon WP + sulfur | 0.06 | 0.0 | 71.0 | 15.0 | 10.7 |
| Nuarimol G + sulfur | 0.07 | 0.0 | 75.6 | 15.2 | 11.5 |
| Nuarimol EC + sulfur | 0.08 | 0.1 | 67.4 | 15.0 | 10.1 |
| Propiconazol EC + sulfur | 0.05 | 0.0 | 69.1 | 15.0 | 10.4 |
| *F* ratio[d] | | | | | |
| All treatments | 32.9*** | ··· | 2.4* | 1.4 | 2.4* |
| None vs. others | 37.7*** | ··· | 19.9*** | 7.3* | 7.1* |
| Sulfur alone vs. sulfur with all systemics | 203.6*** | ··· | 1.9 | 0.0 | 1.2 |
| Among triadimefon and nuarimol treatments | 0.0 | ··· | 3.6* | 0.4 | 2.8 |
| Triadimefon vs. nuarimol | 0.0 | ··· | 0.0 | 0.0 | 0.0 |
| Granules vs. spray | 0.0 | ··· | 7.4** | 1.2 | 6.7** |
| (Triadimefon vs. nuarimol) × (granules vs. spray) | 0.0 | ··· | 3.3 | 0.0 | 1.7 |
| LSD (0.05) | 0.38 | ··· | 5.2 | 0.7 | 6.7 |
| C.V. (%) | 43.8 | ··· | 5.1 | 3.0 | 1.0 |
| | 1983[c] | | | | |
| Check | 1.91 | 32 | 61.0 | 14.8 | 9.1 |
| Sulfur | 0.81 | 6 | 72.1 | 15.1 | 10.9 |
| Triadimefon G | 0.12 | 0.1 | 76.2 | 15.5 | 11.8 |
| Triadimefon + sulfur | 0.15 | 0.2 | 79.9 | 15.8 | 12.6 |
| Nuarimol G | 0.19 | 0.4 | 74.7 | 15.4 | 11.5 |
| Nuarimol + sulfur | 0.40 | 1.6 | 79.8 | 15.2 | 12.2 |
| *F* ratios[d] | | | | | |
| All treatments | ··· | ··· | 24.0*** | 5.9*** | 40.3*** |
| None vs. others | 92.0*** | ··· | 98.3*** | 15.3*** | 158.7*** |
| Sulfur alone vs. treatments with systemics | 12.7*** | ··· | 11.9*** | 4.8* | 24.4*** |
| Among treatments with systemics | 0.7 | | 3.3* | 3.1* | 6.1** |
| Triadimefon vs. nuarimol | 1.2 | ··· | 0.3 | 5.2* | 3.5 |
| Sulfur | 0.6 | ··· | 9.2*** | 0.5 | 14.5*** |
| (Triadimefon vs. nuarimol) × sulfur | 0.4 | ··· | 0.3 | 3.4 | 0.2 |
| LSD (0.05) | 0.44 | ··· | 4.2 | 0.4 | 0.6 |
| C.V. (%) | 61.6 | ··· | 4.7 | 2.1 | 4.3 |

[a] Sulfur was flowable applied biweekly at 11.5 kg in 486 L of water per hectare in 1981 and 1982 and in 243 L of water per hectare in 1983 (seven applications in 1981 and 1982 and six in 1983). Systemic fungicides were applied at layby to plant crowns as granules (G) at 1.12 per hectare.

[b] Average of biweekly mildew ratings weighted by weeks from observation to 1 October. % MLAD = percent mature leaf area diseased.

[c] In 1981, layby was 61 days after planting (DAP), the first sign of disease was 68 DAP, and harvest was 169 DAP. In 1982, layby was 57 DAP, the first sign of disease was 71 DAP, and harvest was 168 DAP. In 1983, layby was 66 DAP, the first sign of disease was 66 DAP, and harvest was 178 DAP.

[d] Statistical significance indicated by * = $P = 0.05$, ** = $P = 0.01$, and *** = $P = 0.001$.

In 1983, triadimefon and nuarimol were again tested as crown-applied granules for yield stimulation, but in this instance, each was applied with and without sulfur. When sulfur alone was compared with the four systemic fungicide treatments, there were significant or highly significant increases of 5.6 t/ha in root yield, 0.4 percentage points in sucrose concentration, and 1.13 t/ha in sugar yield. With sulfur alone, it is difficult to completely control powdery mildew. In 1982 and 1983 (Table 4), average disease ratings for sulfur alone were quite low but significantly higher than when a systemic was used. This raises the possibility that what appears to be growth stimulation by a systemic could be due to more complete disease control. Other work, however, has indicated that sugar beet can tolerate a midseason disease severity of 30% MLAD without a reduction in sugar yield (6). In the 1983 trial (Table 4), disease severity in the sulfur-alone treatment only rose briefly to 15% on 7 September and dropped to 2% after 2 wk. Thus it does not appear likely that the increased yields associated with the systemics were due to the slight improvement in disease control observed in this trial. Between the two systemic fungicides, the only significant effect was a 0.35-percentage point increase in sucrose concentration in favor of triadimefon. Sulfur affected the two systemics similarly [ie, (triadimefon vs. nuarimol) × sulfur = NS] and on the average gave a highly significant improvement of 5.4 and 0.75 t/ha in root and sugar yield, respectively.

A comparison of the stimulatory effect of triadimefon granules during the 2 yr in which this effect occurred (1981 and 1983) shows a similar effect, with root yield increases of 7.5 vs. 7.8 t/ha, respectively, for sulfur alone compared with triadimefon plus sulfur.

We do not have data to clearly indicate reasons for the apparent synergistic effect of the systemics when used with sulfur that occurred in 1983. One might speculate that the increase in root yield of 3.35 t/ha [((76.2 + 74.7)/2) − 72.1] for the granules alone resulted from better disease control, but this seems doubtful because of the small amount of disease present in the sulfur-treated plots as discussed earlier. The additional increase of 4.4 t/ha [(79.9 + 79.8 − 76.2 − 74.7)/2] when sulfur was used with the systemics is difficult to explain. One possibility is that the increased albedo of the crop canopy resulting from biweekly applications of flowable sulfur reduced heating and stomatal resistance, thereby increasing $CO_2$ fixation. This possible effect obviously needs further research as do the growth-regulating effects of the systemic fungicides. The work of others, our subjective evaluations, and a limited amount of growth study data obtained from some of these trials suggests that the sterol inhibitors should be studied further for their ability to delay leaf senescence (2) and enhanced maintenance of synthetic processes (3).


## ACKNOWLEDGMENTS

We thank A. Abshashi and G. A. Peterson for extensive field assistance. This work was supported in part by the California Beet Growers Association, the California Sugarbeet Processors, Eli Lilly and Company, and Ciba-Geigy Corporation.


## LITERATURE CITED


1. Brandes, W., Steffens, W., Fuhr, F., and Scheinpflug, H. 1978. Further studies on translocation of ($^{14}$C) triadimefon in cucumber plants. Pflanzenschutz Nachr. Bayer 31:132-144.
2. Buchenauer, H., and Grossmann, F. 1977. Triadimefon: Mode of action in plants and fungi. Neth. J. Plant Pathol. 83(Suppl. 1):93-103.
3. Forster, H., Buchenauer, H., and Grossmann, F. 1980. Side effects of the systemic fungicides triadimefon and triadimenol on barley plants. II. Cytokinin-like effects. Z. Pflanzenkr. Pflanzenschutz 87:640-653.
4. Frate, C. A., Leach, L. D., and Hills, F. J. 1979. Comparison of fungicide application methods for systemic control of sugar beet powdery mildew. Phytopathology 69:1190-1194.
5. Hills, F. J., Chiarappa, L., and Geng, S. 1980. Powdery mildew of sugar beet: Disease control and crop loss assessment. Phytopathology 70:680-682.
6. Hills, F. J., and Worker, G. F., Jr. 1983. Disease thresholds and increases in fall sucrose yield related to powdery mildew of sugar beet in California. Plant Dis. 67:654-656.
7. Kontaxis, D. G., Meister, H., and Sharma, R. K. 1974. Powdery mildew epiphytotic on sugarbeets. Plant Dis. Rep. 58:904-905.
8. Kraus, P. 1981. Studies on uptake and translocation of Bayleton® in grape plants. Pflanzenschutz Nachr. 34:197-212.
9. Little, T. M., and Hills, F. J. 1978. Pretransformed scales. Pages 162-164 in: Agricultural Experimentation, Design and Analysis. John Wiley & Sons, New York.
10. Paulus, A. O., Harvey, O. A., Nelson, J., and Meek, V. 1975. Fungicides and timing for control of sugarbeet powdery mildew. Plant Dis. Rep. 59:516-517.
11. Ruppel, E. G., Hills, F. J., and Mumford, D. L. 1975. Epidemiological observations on the sugarbeet powdery mildew epiphytotic in western U.S.A. in 1974. Plant Dis. Rep. 59:283-286.
12. Siegel, M. R. 1981. Sterol-inhibiting fungicides: Effects on sterol biosynthesis and sites of action. Plant Dis. 65:986-989.