Comparison of Fungicide Application Methods for Systemic Control of Sugar Beet Powdery Mildew

C. A. Frate, L. D. Leach, and F. J. Hills

Research assistant and professor emeritus, respectively, Department of Plant Pathology, and extension agronomist, University of California, Davis 95616.

We thank Dennis Hall, Joyce Arakawa Chan, and Woodrow Ishisaka for their assistance. We also thank the California Sugar Beet Research Committee and Chemagro Agricultural Division of Mobay Chemical Corporation for financial assistance.
Accepted for publication 14 May 1979.

ABSTRACT

FRATE, C. A., L. D. LEACH, and F. J. HILLS. 1979. Comparison of fungicide application methods for systemic control of sugar beet powdery mildew. Phytopathology 69:1190-1194.

Several methods of applying four systemic fungicides to control sugar beet powdery mildew were tested in the greenhouse and field over a 5-yr period. When applied as seed treatments, benomyl, ethirimol, and triadimefon had no effect on yield or disease levels under field conditions. However, when used as a preplant soil treatment, triadimefon at 1.12 kg/ha reduced disease levels and resulted in yields comparable to sulfur-sprayed controls. When applied as foliar sprays (0.28 kg/ha) twice during the growing season, nuarimol and triadimefon provided disease control comparable to that of two sulfur applications, each at 44.8 kg/ha. All foliar sprays protected leaves for approximately 4–6 wk and required repeated applications for effective control. When applied directly to the crowns of 8-wk-old sugar beets, low-concentration (5%) granules of nuarimol (0.56 and 1.12 kg/ha) or triadimefon (0.56, 1.12, and 2.24 kg/ha) resulted in low levels of disease throughout the season and in yields as high as or, in some trials, significantly higher than the sulfur sprays tested.

Additional key words: Erysiphe betae, E. polygoni.

Since 1974, powdery mildew has been an important disease of sugar beets in the western United States (6,10). In field trials in California (3,4,12), this disease caused yield reductions of 20–30%. At present, the disease can be controlled adequately by dusting or spraying with sulfur. Timing of the initial sulfur application can be critical, however, and a delay in starting treatment can result in yield reductions of 2.2–7.4 metric tons per hectare of fresh root weight and 0.9–1.5 metric tons per hectare of gross sugar (3,12). The first application is not required until sugar beets are about 7–10 wk old because, in the field, mildew does not develop in younger plants (10,11). A second application 3–6 wk later usually is required, and a third application may be necessary under some conditions.

Because of the serious occurrence of this disease in the United States, several studies on the efficacy of systemic fungicides, usually applied as foliar sprays, have been conducted (3–5,8). Because repeated applications are needed, however, foliar use of these fungicides offers little advantage over sulfur. For this reason, alternative methods of application were sought in an effort to increase the efficiency of the compounds. In the greenhouse, where beet seedlings can become infected within 14 days of emergence, use of systemics as seed treatments protected plants for 50–60 days (2). Additionally, soil placement of fertilizer granules treated with a systemic fungicide protected sugar beets for over 200 days. Whether such treatments would provide acceptable control of disease under field conditions was not known.

This paper reports on 4 yr of field trials in which various methods of applying systemic fungicides were tested and compared to applications of wettable sulfur. The methods were seed treatment, preplant soil placement of granules, foliar spray, and crown treatment with granules.

MATERIALS AND METHODS

Fungicides tested. Four systemic fungicides were used: (i) benomyl (Benlate®, methyl-1-[butylcarbamoyl]-2-benzimidazole-carbamate, E. I. du Pont de Nemours & Co., 1007 Market Street, Wilmington, DE 19898), (ii) ethirimol (Milstem®, 5-butyl-2-ethylamino-4-hydroxy-6-methylpyrimidine, Imperial Chemical Industries, P.O. Box 208, Goldsboro, NC 27530), (iii) nuarimol (EL-228, α-[2 chlorophenyl]-α-[4-chlorophenyl]-5-pyrimidine-methanol, Eli Lilly & Co., P.O. Box 708, Greenfield, IN 46140), and (iv) triadimefon (Bayleton®, BAY MEB 6447, 1-[4-chlorophenoxy]-3, 3-dimethyl-1-[1 *H*-1,2,4-triaxol-1y1]-2-butanone, Chemagro Agricultural Division of Mobay Chemical Corp., P.O. Box 4193, Kansas City, MO 64120). All rates refer to active ingredients of fungicides.

Fungicide application. When applied as seed treatments, the fungicides were suspended in water and sprayed onto seeds in a rotating mixer. Wettable powder formulations of 50% benomyl, 80% ethirimol, and 25% triadimefon were used at rates of 32, 32, and 1 g/kg seed, respectively. These rates had been found effective and safe in greenhouse trials (2). Seeds were air-dried immediately after fungicide application.

Foliar sprays of triadimefon (50% WP), nuarimol (9.5% EC), and wettable sulfur (92%) suspended in water were applied with a hand-pumped or CO_2- pressurized backpack sprayer.

For soil placement, low-concentration (5%) granules were placed with a Noble applicator (Noble Cultivator Ltd., Nobleford, Alta., Canada T0L 1S0) or a Clampco Select a Dial (Clampco, Inc., Box 2134, Salinas, CA 93910) about 7.5 cm beneath the soil surface in the center of the row 1 or 2 days before seeding.

Low-concentration granules also were applied directly to sugar beet crowns in a manner similar to that used with systemic insecticides (9). A Select-a-Dial applicator metered the granules into 6-cm diameter flexible hoses centered directly over plant rows and adjusted so the ends brushed the tips of the tallest leaves of 8-wk-old sugar beets. Leaves and petioles channeled most of the granules into the crown area. Limited sampling indicated that approximately 58% of the granules applied in this manner remained in the plant crowns and the rest fell through the foliage to the soil.

Plot layout and disease evaluation. All trials were conducted at Davis, CA, in Reiff and Zamora loam soil (1). Cultivar US H10 was seeded on 76-cm single-row beds in plots 15.2 m long. Each plot was four rows wide, and data were taken from only the two center rows.

00031-949X/79/000211$03.00/0

The plots were furrow-irrigated throughout the experimental periods, and measurable rainfall was limited to 3 days in August 1976 (1.3 cm) and 1 day in September 1977 (1.4 cm). At harvest, roots were counted and weighed in the field. Samples were sent to a commercial sugar refinery in nearby Woodland, CA, for tare and sucrose determination.

All disease in the plots resulted from natural infection. At periods throughout each season, plants were rated for disease severity by estimating the area of mature (fully expanded) leaves covered by mildew. Leaves were evaluated on a pretransformed scale (7) of 0, 10, 35, 65, 90, and 100, representing the percentage of mature leaf area diseased (% MLAD). At least 25 recently matured leaves were read per plot, and a mean % MLAD value for each plot was calculated as follows:

$$\text{Mean \% MLAD} = 100 \left[\left(\Sigma D_i n_i \right) / \Sigma n_i \right]$$

where D_i = each disease rating and n_i = number of leaves per rating. The periodic disease ratings were used to determine a disease progression curve for each treatment and were averaged to give a mean powdery mildew rating for the season.

In 1975, seed treatment and soil placement with systemic fungicides were compared to sulfur sprays applied three times in a replicated trial. Benomyl, ethirimol, and triadimefon were applied to seed as previously described. Triadimefon granules, 1.12 kg/ha, were used for preplant soil placement. Sulfur was applied at 11.2 kg/ha on 23 July, 13 August, and 3 September. Seeding was on 1 May, and plots were harvested on 2 October.

1976 Trial. Three methods of applying triadimefon were evaluated. Preplant soil placement of granules at 1.12 kg/ha was done 26 April, 2 days before seeding. Granules were applied in the crown 28 June, 9 wk after seeding, at rates of 0.56, 1.12 and 2.24 kg/ha. Lastly, sprays were applied to the foliage at 0.28 kg/ha in 936 L of water on 7 July (7 days after mildew appeared) and on 3 August. Foliar sprays of wettable sulfur at 11.2 kg/ha in 468 L also were applied on 7 July and 3 August. Each treatment was replicated six times. Half of each plot was harvested on 22 September and the remainder on 20 October; data are from the second harvest.

1977 Trial. Triadimefon and nuarimol were applied to plants as foliar sprays or crown treatments. Plots were seeded on 1 May and harvested on 13 October. In crown treatments, granules of triadimefon and nuarimol at 0.56 and 1.12 kg/ha were applied at the first sign of mildew on 28 June. For foliar sprays, both triadimefon and nuarimol were applied twice at the rate of 0.28 kg/ha per application, for a total dosage of 0.56 kg/ha. Sprays were applied on 28 June and 10 August. The sulfur treatment consisted of two applications, one on 28 June and the other on 10 August; each application was 44.8 kg/ha. Treatments were replicated four times, and disease levels were evaluated at 2-wk intervals from 12 July to 4 October.

1978 Trial. Crown applications of triadimefon granules were compared with sulfur sprays applied one, two, three, or four times at 4-wk intervals. Plots were seeded on 24 May and harvested on 24 October. Crown treatments of 0.56 and 1.12 kg/ha of triadimefon granules were applied as in previous trials on 6 July, 43 days after seeding and 25 days before the first observation of powdery mildew. An additional set of plots treated with triadimefon granules also received one sulfur spray on 11 September to determine if added late-season protection would improve mildew control and sugar beet production.

RESULTS

In 1975, seed treatments did not reduce disease levels or increase yields compared with check plots. Three applications of sulfur kept the disease level low until harvest and resulted in increased root weight and sucrose yields. The triadimefon preplant soil treatment reduced the level of disease early in the season but decreased in effectiveness as the season progressed; yet, plants in this treatment produced nearly as much total sucrose as those with three sulfur applications. Since this was a preliminary trial, data are not

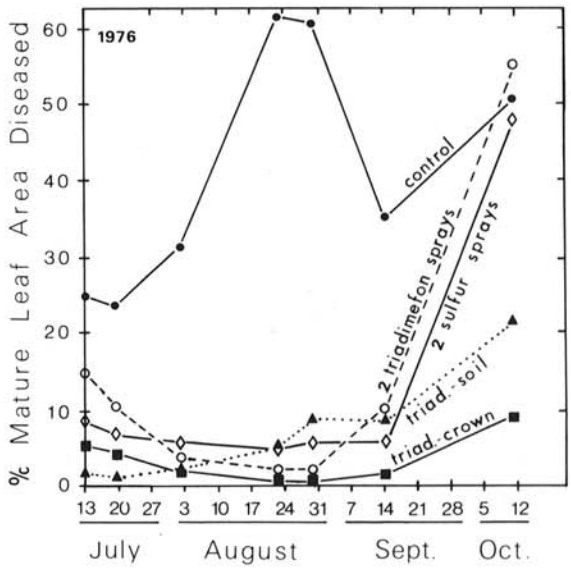

Fig. 1. Disease progression curves for selected 1976 treatments: control, two triadimefon sprays (0.28 kg/ha/application), two sulfur sprays (11.20 kg/ha/application), triadimefon preplant soil placement (1.12 kg/ha), and triadimefon crown placement (1.12 kg/ha). Crown application was made on 28 June; sprays were applied on 7 July and 3 August.

TABLE 1. Yields and mean powdery mildew ratings from sugar beets treated with soil, foliar spray, and crown applications of the systemic fungicide triadimefon and foliar sprays of sulfur in 1976[a]

Treatment	Rate per application[b] (kg/ha)	Date(s) applied	Mean mildew rating[c] (% MLAD)	Yields		
				Fresh root wt (t/ha)	Sucrose (%)	Gross sucrose (t/ha)
Control	...	...	41.5	69.1	13.5	9.3
Sulfur spray	11.20	7/7, 8/3	11.6	80.9	13.9	11.3
Triadimefon spray	0.28	7/7, 8/3	13.7	87.4	14.5	12.7
Triadimefon soil	1.12	4/26	7.1	86.8	14.5	12.6
Triadimefon crown	0.56	6/28	5.6	88.3	14.6	12.9
Triadimefon crown	1.12	6/28	2.6	91.0	14.7	13.4
Triadimefon crown	2.24	6/28	1.1	90.8	15.2	13.7
LSD 5%				5.3	0.5	0.9

[a] US H10 seeded 28 April and harvested 20 October. Values are means of six replicates.
[b] Wettable sulfur was applied in 468 L water/ha. For the triadimefon spray, a 50% WP was applied in 936 L water/ha. For soil and crown treatments, 5% granules were used.
[c] Averages of ratings taken on 13 and 19 July, 2, 23, and 30 August, 14 September, and 11 October, expressed in terms of percentage of mature leaf area diseased.

presented in tabular form. In a concurrent study, side-dressing with granules of 8-wk-old plants was no more effective than preplant soil application (2).

1976 Trial. Powdery mildew was first observed 30 June. All triadimefon treatments had significantly higher sucrose content and gross sucrose yields than the sulfur treatment (Table 1). Among the three methods of triadimefon application, preplant soil placement yielded less gross sucrose than the crown treatment applied at the same rate. The 0.56 kg/ha rate applied once to crowns resulted in yields equivalent to those with two 0.28 kg/ha foliar sprays.

Disease developed rapidly on untreated plants but appeared to decrease slightly in August and early September (Fig. 1), probably because of loss of most older leaves in control plots and subsequent evaluation of younger, less affected leaves. When applied as a spray, triadimefon appeared similar to sulfur in control of disease, yet sugar yields were higher than those with sulfur treatment. There is no obvious explanation for this effect. The early protection provided by preplant soil placement slowly decreased throughout the season, and yields were comparable to two triadimefon sprays. Crown treatments had the lowest disease levels, and these levels decreased as dosage rates increased. The disease curve for the intermediate (1.12 kg/ha) rate is shown in Fig. 1. By late August, the 0.56 kg/ha rate began to lose effectiveness, but the final reading was still below that of the preplant soil treatment applied at twice the rate. The correlation coefficient for the mean mildew ratings and the gross sucrose yields was -0.95 ($P = 0.01$).

1977 Trial. All fungicide treatments resulted in yields significantly higher than the untreated control, which produced 31% less gross sucrose than the highest yielding treatment (Table 2). There was no significant difference in percentage of sucrose yield between treated and untreated plants, although the untreated plants had over 1% less than the highest producing treatments. At the rates tested, two foliar applications of the systemic fungicides were no better than two sulfur sprays. The yields with crown applications of triadimefon were significantly higher than those with foliar sprays. With the four crown treatments, there were no significant differences among the fungicides or rates tested. The correlation coefficient between mean mildew ratings and gross sucrose yields was -0.95 ($P = 0.001$).

The first application of sulfur on 28 June delayed the appearance of disease and slowed the rate of increase for approximately 4 wk (Fig. 2). The disease level increased rapidly after 26 July but dropped sharply after the second sulfur application on 10 August, which appeared to retard the development of powdery mildew for approximately 6 wk. By the end of the season, the disease level increased rapidly. The disease curves for foliar applications of the systemic fungicides were similar and are represented in Fig. 2 by the 0.28 kg/ha per application rate of triadimefon. This treatment had roughly the same effects on the disease as the sulfur sprays. The 6-wk interval between the first and second sprays with either sulfur or triadimefon obviously was too long for continuous protection. The crown treatments are represented in Fig. 2 by the 1.12 kg/ha rate of triadimefon, the highest yielding treatment. The long-term protection provided by this method is shown by the low level of disease through most of the season. Other crown treatments had similar curves, but final disease ratings were related to dosage.

1978 Trial. Disease control and yields improved with each of three sulfur applications as compared with the unsprayed control (Table 3). A treatment with four sulfur applications, not included in the table, had no further effect. As in previous years, triadimefon granules in the crowns of plants gave outstanding, season-long

TABLE 2. Yields and mean powdery mildew ratings from sugar beets treated with foliar sprays and granular crown applications of the systemic fungicides nuarimol and triadimefon and foliar sprays of sulfur in 1977[a]

Treatment	Rate per application[b] (kg/ha)	Date(s) applied	Mean mildew rating[c] (% MLAD)	Yields		
				Fresh root wt (t/ha)	Sucrose (%)	Gross sucrose (t/ha)
Control	...	...	42.8	61.2	13.6	8.3
Sulfur spray	44.80	6/28, 8/10	24.3	72.9	14.5	10.5
Nuarimol spray	0.28	6/28, 8/10	11.8	76.2	14.6	11.1
Triadimefon spray	0.28	6/28, 8/10	18.4	69.1	14.4	9.9
Nuarimol crown	0.56	6/28	12.5	78.7	14.0	11.0
Nuarimol crown	1.12	6/28	3.1	79.6	14.5	11.6
Triadimefon crown	0.56	6/28	4.8	77.8	14.3	11.1
Triadimefon crown	1.12	6/28	2.5	81.6	14.8	12.1
LSD 5%				5.0	ns[d]	1.0

[a] US H10 seeded 1 May and harvested 13 October. Values are means of four replicates.
[b] All sprays were applied in 374 L water/ha.
[c] Averages of ratings taken on 12 and 26 July, 9 and 23 August, 6 and 20 September, and 4 October, expressed in terms of percentage of mature leaf area diseased.
[d] Not significant.

TABLE 3. Yields and mean powdery mildew ratings from sugar beets treated with granular crown applications of the systemic fungicide triadimefon and foliar sprays of sulfur in 1978[a]

Treatment	Rate per application[b] (kg/ha)	Date(s) applied	Mean mildew rating[c] (% MLAD)	Yields		
				Fresh root wt (t/ha)	Sucrose (%)	Gross sucrose (t/ha)
Control	...	...	70.9	57.6	15.6	9.0
Sulfur spray	11.20	7/19	52.6	59.9	15.4	9.2
Sulfur spray	11.20	7/19, 8/14	45.1	62.2	16.1	10.0
Sulfur spray	11.20	7/19, 8/14, 9/11	24.7	68.0	15.9	10.8
Triadimefon crown	0.56	7/6	10.4	68.0	16.5	11.2
Triadimefon crown	1.12	7/6	3.8	69.7	16.5	11.5
LSD 5%				3.3	0.5	0.5

[a] US H10 seeded 24 May and harvested 24 October. Values are means of four replicates.
[b] All sprays were applied in 374 L water/ha.
[c] Averages of ratings taken at 2-wk intervals from 31 July to 24 October, expressed in terms of percentage of mature leaf area diseased.

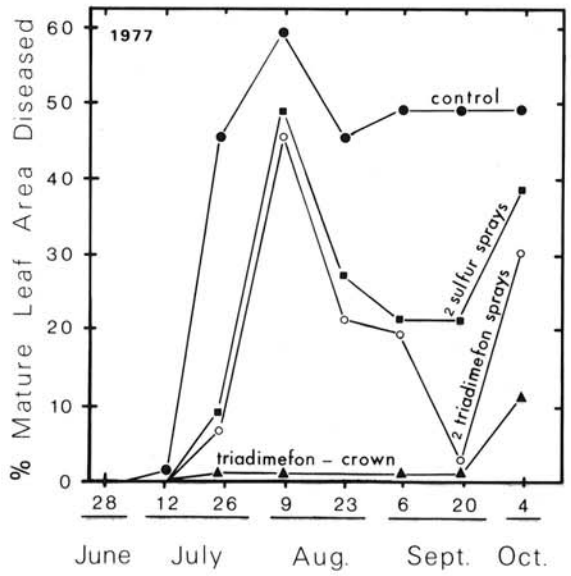

Fig. 2. Disease progression curves for selected 1977 treatments: control, two sulfur sprays (44.8 kg/ha/application), two triadimefon sprays (0.28 kg/ha/application), and triadimefon crown placement (1.12 kg/ha). Sprays were applied on 28 June and 10 August; crown application was made on 28 June.

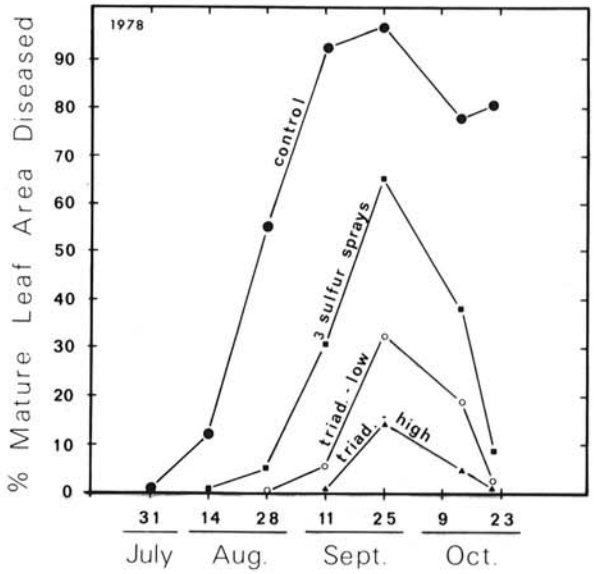

Fig. 3. Disease progression curves for selected 1978 treatments: control, three sulfur sprays (11.20 kg/ha/application), and two rates of triadimefon crown placements (low = 0.56 kg/ha and high = 1.12 kg/ha). Crown applications were made on 6 July; sprays were applied on 19 July, 17 August, and 11 September.

disease control (Fig. 3). Both rates (0.56 and 1.12 kg/ha) applied to the crowns produced higher sucrose concentration, sugar yield, and root yield than the three sulfur sprays. Disease control late in the season was slightly better with the 1.12 kg/ha rate but the yield was not significantly higher. Because the late-season sulfur application to plots previously treated with granules did not increase sugar yield and only slightly improved disease control, these data are not included in Table 3 or Fig. 3. The correlation coefficient for mean mildew ratings and gross sucrose yields was -0.98 ($P = 0.001$).

DISCUSSION

Results from all 4 yr showed that yield losses of 20–30% in gross sucrose can occur when sugar beet powdery mildew is not controlled. These data agree with other reports from California (3,4,12). Yield loss and severity of foliar symptoms were strongly correlated. One exception occurred in the 1976 trial; disease ratings were similar for the two foliar spray applications of sulfur and triadimefon but sucrose percentage and gross sucrose yield in triadimefon-sprayed plots were significantly higher than in sulfur-sprayed plots (Table 1.)

Although sugar beet powdery mildew currently is controlled with sulfur, systemic fungicides would be desirable alternatives if they were more effective, provided longer protection, and were comparable economically. Our studies indicate that the method of fungicide application influences the effectiveness and duration of sugar beet powdery mildew control. Maximum control was attained with a single application of 0.56 or 1.12 kg/ha of granular systemic fungicide directly in the crown. Preplant and side-dressed soil applications provided control for much of the season but were not as effective or long-lasting as crown treatments. Foliar sprays were very effective in controlling disease but had to be applied repeatedly and, therefore, offered little advantage over sulfur. Seed treatments, although effective in controlling powdery mildew on greenhouse seedlings for 50–60 days (2), were ineffective in field trials, apparently because the plants were so large by the time disease developed (7–10 wk) that the concentration of fungicide was too low to be effective.

A single crown application of a systemic fungicide provided season-long protection. Most of the granules were retained in the crown, and granules could still be found lodged at the base of petioles in late August and early September. The shape of sugar beets is conveniently suited to crown applications, and the chances for granules to remain in the crown increase as the amount of foliage increases. Fortunately, plants do not become infected until they are 7–10 wk old and, by that time, considerable foliage has developed. Because the crown treatment provides long-term protection, early application before the appearance of disease is sufficient for the entire season. Application of granules in the manner used in our study reduces the hazard of drift to nearby inhabited areas or to adjacent fields as compared with dust applications.

Whether or not crown applications for sugar beet powdery mildew are commercially feasible depends on effectiveness, usefulness under different environments and irrigation practices, and the cost:benefit ratio under specific conditions. These factors can be fully determined only by testing the fungicides and methods of application in commercial fields. At the time of writing, none of the systemic fungicides used in our study has been registered for control of sugar beet powdery mildew.

LITERATURE CITED

1. ANDREWS, W. F. 1972. Soil Survey of Yolo County, California. U.S. Government Printing Office, Washington, DC. 102 pp.
2. FRATE, C. A. 1977. Systemic fungicides for the control of powdery mildew of sugarbeet. M.S. thesis, University of California, Davis. 69 pp.
3. HILLS, F. J., D. H. HALL, and D. G. KONTAXIS. 1975. Effect of powdery mildew on sugarbeet production. Plant Dis. Rep. 59:513:515.
4. HILLS, F. J., D. H. HALL, L. D. LEACH, C. A. FRATE, R. T. LEWELLEN, and L. CHIARAPPA. 1976. Powdery mildew of sugar beet—here to stay? Calif. Agric. 30(10):16-18.
5. KONTAXIS, D. G. 1976. Chemical control of powdery mildew on sugar beets. Calif. Agric. 30(1):13-14.
6. KONTAXIS, D. G., H. MEISTER, and R. K. SHARMA. 1974. Powdery mildew epiphytotic on sugarbeets. Plant Dis. Rep. 58:904-905.
7. LITTLE, T. M., and F. J. HILLS. 1978. Agricultural Experimentation; Design and Analysis. John Wiley & Sons, New York. 350 pp.
8. PAULUS, A. O., O. A. HARVEY, J. NELSON, and V. MEEK. 1975. Fungicides and timing for control of sugarbeet powdery mildew. Plant Dis. Rep. 59:516-517.
9. REYNOLDS, H. T., T. R. FUKOTO, and G. D. PETERSON, JR. 1960. Effect of topical applications of granulated systemic insecticides and of conventional applications of other insecticides on control of insects and spider mites on sugar beet plants. J. Econ. Entomol. 53:725-729.
10. RUPPEL, E. G., F. J. HILLS, and D. L. MUMFORD. 1975. Epidemiological observations on the sugarbeet powdery mildew

epiphytotic in Western U.S.A. in 1974. Plant Dis. Rep. 59:283-286.
11. RUPPEL, E. G., and B. J. TOMASOVIC. 1977. Epidemiological factors of sugar beet powdery mildew. Phytopathology 67:619-621.
12. SKOYEN, I. O., R. T. LEWELLEN, and J. S. McFARLANE. 1975. Effect of powdery mildew on sugarbeet production in the Salinas Valley of California. Plant Dis. Rep. 59:506-510.