Control of Leaf Rust on Spring Wheat by Seed Treatment with 4-N-butyl-1,2,4-triazole

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This is a report on the current status of research concerning use of chemicals that require registration under the Federal Insecticide, Fungicide, and Rodenticide Act, as amended by the Federal Environmental Pesticide Control Act. Not all of the chemicals mentioned here are presently so registered with the Environmental Protection Agency. No recommendations for use of these chemicals are implied in this report.

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ABSTRACT

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Seedling assays showed that 4-*n*-butyl-1,2,4-triazole (RH-124) was superior as a systemic protectant against wheat leaf rust in foliar, soil, and seed applications compared to triarimol, oxycarboxin, and benomyl. RH-124, however, had a relatively short duration of effectiveness inside the wheat plant. In field tests, the effective dosage for seed treatment with RH-124 was 20-25% of that required for the same level of effectiveness as a spray applied after rust was present. A seed treatment at 140 g/hectare(ha) effectively prevented crop losses due to leaf rust. Soil residues from spray applications at 280 and 560 g/ha suppressed leaf rust development on wheat planted in the succeeding season. Seed treatment with RH-124 had no discernible effect on plant development when seed was planted in moist soil, but stand densities and seedling growth were reduced when seed was planted in dry soil. More RH-124 was required for the same level of control of leaf rust on cultivar Kota than on the less susceptible cultivars Thatcher and Selkirk. The results indicate that seed treatment with RH-124 has a high potential for control of leaf rust on spring wheats in the north central USA.

Additional key words: Puccinia recondita, Triticum aestivum, systemic fungicides.

A systemic fungicide, 4-*n*-butyl-1,2,4-triazole (RH-124), is specifically effective against wheat leaf rust caused by *Puccinia recondita* Rob. ex Desm. f. sp. *tritici* Eriks (14). Trials with spray applications of RH-124 indicated that efficacy decreased as the time of application was delayed after planting of wheat (12); this suggested potential for the chemical as a seed treatment for rust control. Seed treatment with large doses of oxycarboxin has given some suppression of rusts on wheat (7, 11), but yields were not improved appreciably. Formulations of RH-124 prepared by the manufacturer (Rohm and Haas Company, Philadelphia, Pa.) for seed treatment were assessed for control of wheat leaf rust. This report gives the results of seedling assays for various systemic properties of RH-124 in comparison to some other systemic fungicides and of field evaluations in 1972 and 1973 of the effectiveness of RH-124 applied as seed treatments in comparison to spray applications made after the start of the leaf rust epidemic.

MATERIALS AND METHODS

The formulations of RH-124 tested in foliar applications were 80% and 70% liquid concentrates in 1972 and 1973, respectively. Special dry formulations of RH-124, 46% a.i. JR5120A in 1972 and 50% WP JR5680 in 1973, were used for seed treatments. Other fungicides assayed were: α-(2,4-dichlorophenyl)-α-phenyl-5-pyrimidinemethanol (triarimol), formulated as a 4.5% emulsion concentrate and a 25% wettable powder; 5,6-dihydro-2-methyl-1,4-oxathiin-3-carboxanilide-4,4-dioxide (oxycarboxin), formulated as 75% wettable powder and seed treatment; and 1-(butylcarbamoyl)-2-benzimidazole carbamic acid (benomyl), formulated as 50% wettable powder. All doses are given as the amount of the active ingredient.

Test seedlings of Thatcher wheat were grown in a mixture of field soil, sand, peat, and manure (3:3:3:1, v/v) in 7.5-cm diameter clay pots for foliar treatments and in 10-cm diameter plastic pots for seed or soil treatments. Conditions were constant at 24 C and a 12-hour light cycle of about 16,500 lx in a growth chamber. The first true seedling leaf was fully expanded at 7 days after planting, at which time the plants were used. Test plants were inoculated in a calibrated spray chamber (13) with a suspension of fresh uredospores of *P. recondita* f. sp. *tritici* carried in a light, nontoxic mineral oil that results in an infection density of about 15 uredia per leaf. Inoculated plants were incubated in a dew chamber for 12 hours at 21 C in the dark, and then returned to the growth chamber. Four replicate, randomized pots, usually with six seedlings each, were used per treatment. Five dosages and an untreated control were used in each assay. The uredia per leaf were counted at 12 days after inoculation. The ED_{50} (6) was used for comparisons. The results are means of two or three separate assays.

Assay procedures.—The procedures listed in Table 1 were conducted as follows:

Protectant-drop.—The plants were inoculated 24 hours after a dosage series of the test material was applied in 10-μliter drops of 500 μg/ml polyoxyethylene sorbitan monolaurate on the adaxial surface 5 cm from the leaf tip. The drops were allowed to dry slowly in the growth chamber. The ED_{50} values for this assay are based on the number of uredia on the uppermost 5 cm of seedling leaf because all compounds tested moved more effectively in a distal than in a proximal direction.

Protectant-drench.—The test compounds were applied to the soil surface in 50 ml of water at planting. Subsequent watering was controlled to prevent leaching of the chemical from the soil. Seedlings were inoculated 7 days after planting.

Eradicant-spray.—The test dosages were applied to infected test plants 3 days after inoculation as a constant uniform deposit in the inoculation spray chamber. Spray deposition was determined by colorimetric analysis at 585 nm of the deposit produced by sprays of a 0.1% aqueous solution of crystal violet. The spray test measured the potential of a compound to penetrate leaf tissue rapidly and eradicate established infections with minimal internal movement.

Eradicant-drop.—The dosage series were applied as in the protectant-drop test, but 48 hours after inoculation. This test demonstrated the capacity of the compound to eradicate infections distally from the point of entrance.

Eradicant-drench.—The dosage series were applied in 50 ml of water 3 days after inoculation. A better ED_{50} for a compound in the eradicant than in the protectant soil drench assay indicates a loss of effectiveness in the soil environment.

Fungitoxicity.—Inhibition of germination was determined by depositing uredospores of *P. recondita* at about 10 spores/mm^2 on 2×2 cm squares of 12.7 μm pure polyethylene sheets and by inverting the squares on 2 ml of test solutions in pyrex glass cups for 24 hours in the dark at 18 C. No evidence of stimulation or inhibition of either frequency or growth rate of spore germination was evident in test extracts of the polyethylene film. Germination was determined for 100 spores in duplicate samples of each dosage.

For seed treatment trials, dry formulations of the compounds were diluted with diatomaceous earth to maintain a fixed ratio of 400 g of formulated material per 100 kg of seed. The seeds were coated with the material by mechanical shaking in plastic vials for 6 minutes. Six treated seeds were planted per pot; watering was controlled to prevent leaching of the chemical from the soil. Plants were thinned to three uniform test seedlings at emergence and were inoculated 7 days after planting.

In field tests, seed of the test cultivars was planted at 112 kg/ha in 2.4×6 m plots with a 16-row seed drill. Four replicate, randomized plots were used per treatment. Seed was treated with dry formulations of RH-124 diluted with the inert carrier to yield a constant ratio of 250 g of material per 100 kg of seed. A portion of the seed treated in 1973 was analyzed for RH-124 in the laboratory of the manufacturer. The actual doses of RH-124 adhering to the seed were 41.25 and 93.75 g/100 kg, respectively, for the 62.5 and 125 g/100 kg rates of application (W. R. Lyman, *personal communication*). Because such data were only available for the 1973 field test, the dosages of RH-124 given for all seed treatments are based on the rate of application. Spray treatments were applied at a rate of 281 liters/ha and a pressure of 21 kg/cm^2 with a mechanical sprayer and 2.4 m boom having eight hollow-cone spray nozzles. Treated controls were sprayed frequently during the season with a coordination product of zinc ion and manganous ethylenebis[dithiocarbamate] (zinc ion-maneb complex) to determine the yield potential of the crop nearly free of all foliar diseases. Leaf rust severities were estimated weekly between the heading and early dough stages of crop development. The center 1.8 × 4.9 m of each plot was harvested with a mechanical plot-combine for yield determinations.

RESULTS

Seedling assays.—Fungicide RH-124 was an effective systemic protectant against wheat leaf rust in the seedling assays at doses one to several magnitudes lower than the doses required for the other compounds (Table 1). The ED_{50} of 0.014 μg/ml for RH-124 in the protectant-immersion tests indicated that very small internal quantities of this compound were required to prevent infection by leaf rust. Similarly, the ED_{50} of 0.0012 μg/leaf in protectant-drop assays indicated that small amounts of RH-124 readily entered, moved distally in foliar tissue, and prevented infection. In the soil-drench assay, the ED_{50} of 3.6 μg/pot showed that RH-124 remained active in the soil and available for plant uptake.

Fungicide RH-124 had negligible effectiveness as an eradicant, even at the highest dosages tested in the spray

TABLE 1. Effective dose of some systemic fungicides in various assays for 50% control of wheat leaf rust on Thatcher wheat seedlings

	Assay procedure						
	Protectant			Eradicant			
Fungicide	Immersion (μg/ml)	Drop (μg/leaf)[a]	Drench (μg/pot)[b]	Spray (μg/10 cm^2)	Drop (μg/leaf)[a]	Drench (μg/pot)[b]	Fungitoxicity (μg/ml)
4-*n*-butyl-1,2,4-triazole	0.014	0.0012	3.6	> 400	190	>2,000	>100
triarimol	0.95	0.030	595	0.74	0.035	960	9.1
oxycarboxin	218	0.86	420	660	1.2	380	18
benomyl	2.7	0.47	1,900	150	0.8	>2,000	6.5

[a]Applied in 10-μliter drops on the adaxial surface 5 cm from the tip of the first seedling leaf.

[b]Applied in 50 ml of water to the surface soil containing three wheat seedlings in a 10-cm diameter plastic pot.

and soil drench tests (Table 1). In the drop assays, the ED_{50} of 0.0012 μg/leaf for RH-124 as a protectant was 10^5 times more effective than that of 190 μg/leaf as an eradicant, whereas the other compounds had similar effectiveness in these two assays. The fungitoxicity assays with uredospores of leaf rust indicated that RH-124 was weakly toxic, whereas the fungitoxicity of the remaining compounds was comparable to their relative order of effectiveness as systemic fungicides (Table 1). Thus, the poor eradicant activity of RH-124 appears to be related to its weak fungitoxicity.

The duration of effectiveness of the four compounds was the time required for a 50% decrease in the effectiveness of the chemical in leaves treated by immersion with the ED_{90} dose (1). A 50% decrease in effectiveness of 0.1 μg/ml RH-124 occurred in 59 hours, of 2.2 μg/ml triarimol in 116 hours, of 500 μg/ml oxycarboxin in 60 hours, and of 20 μg/ml benomyl in 176 hours. Thus, RH-124 had relatively low persistence in treated leaves.

As seed treatments, the ED_{50} against wheat leaf rust of the four test compounds again showed the superiority of RH-124 as a systemic protectant (Table 2). In this test, about 1.6 μg of RH-124 would be present per pot at the ED_{50} dose of 0.84 g/100 kg of seed; this dose is close to the ED_{50} of 3.6 μg/pot observed in the soil drench assay. Although triarimol was moderately effective in this test, plants were stunted at the higher doses required for tests of effectiveness in the field.

The effectiveness of RH-124 was assayed against leaf rust infection in 36 hard red spring and winter wheats by the protectant-drop procedure. Little variation from the effectiveness of RH-124 in Thatcher was found, except for higher ED_{50}'s in cultivars Kota, Ceres, Trapper, and Warrior. A comparison was made of the cultivars Thatcher and Kota on the effectiveness of RH-124 applied as a soil drench and as a protectant drop on foliage; the ED_{50} values were 2 and 15 μg/pot as a soil drench and 0.0016 and 0.012 μg/leaf as a protectant drop with Thatcher and Kota, respectively. Thus, about seven times more RH-124 was required for effectiveness against leaf rust in seedlings of Kota than in Thatcher.

No phytotoxicity was noted from any of the doses of RH-124 in the seedling assays. Samples of seed treated with RH-124 for the field tests were routinely planted in pots and germinated in the greenhouse to determine any possible effects on germination or seedling vigor. In these tests, 25 seeds were planted per 10 cm pot, four replicate pots per treatment, and seedling emergence and height were determined 12 days later. When Thatcher seed was treated and the pots were watered immediately after planting in 1971, 1972, and 1973, no effect was discerned in the percentage of germination or vigor of growth. In 1973, a second set of treated seed was planted and watered 48 hours later. The soil mixture used was damp, but not sufficiently moist to support rapid germination. Although no significant effect on emergence was observed in this test, a significant 14% reduction in the length of the first leaf was observed in the 125 g/100 kg treatment. The results indicated that soil conditions unfavorable for rapid seed germination could result in

TABLE 2. Effective dose of some systemic fungicides as seed treatments for 50% control of wheat leaf rust on Thatcher wheat seedlings

Fungicide	ED_{50} (g/100 kg)
4-*n*-butyl-1,2,4-triazole	0.84
triarimol	12.3
oxycarboxin	108
benomyl	>200

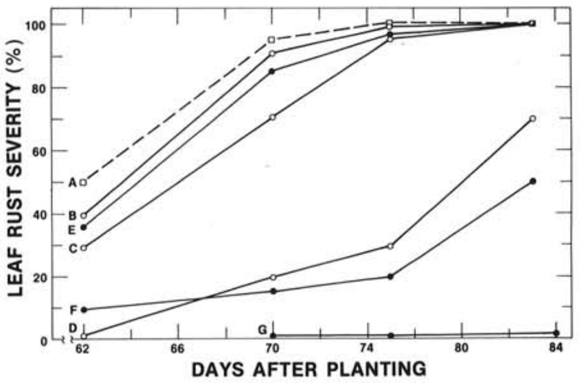

Fig. 1. Effect of RH-124 treatments on leaf rust development between the growth stages of anthesis and early dough of Thatcher wheat, 1972. Legend: A = untreated control; B, C, and D = seed treated with RH-124 at 15, 47, and 140 g/ha, respectively; E, F, and G = sprays applied 19 days after planting at 154, 469, and 1,401 g/ha, respectively.

TABLE 3. Effectiveness of 4-*n*-butyl-1,2,4-triazole (RH-124) in seed and spray treatments for the control of leaf rust on Thatcher wheat

Treatment	Application: Method	Application: Amount (g/ha)	Yield (kg/ha)
1972			
Treated control[a]	Spray	1,793	2,468 a[c]
RH-124	Spray[b]	1,401	1,399 b
RH-124	Spray	469	1,540 b
RH-124	Seed	140	1,291 bc
RH-124	Seed	47	915 cd
RH-124	Seed	15	834 d
RH-124	Spray	154	800 d
Untreated	...	...	787 d
1973			
Treated control[a]	Spray	1,793	2,199 a
RH-124	Seed	140	1,607 b
RH-124	Spray[b]	560	1,480 b
RH-124	Spray	280	1,311 bc
RH-124	Spray	70	1,170 cd
Untreated	...	...	1,137 cd
RH-124	Seed	70	1,103 cd
RH-124	Spray	140	1,056 d

[a]Treated controls sprayed with zinc ion-maneb complex at about weekly intervals from tillering to soft dough stages of crop development.

[b]All sprays of RH-124 applied at 19 days after planting in 1972 and at 35 days in 1973.

[c]Small letters indicate Duncan's multiple range groupings of treatments. Values followed by the same letter do not differ significantly at $P = 0.05$.

toxic effects from RH-124 applied to the seed.

Field performance.—Preliminary trials in 1971 (9) indicated a potential of RH-124 formulations to control leaf rust as seed treatments in the field. However, these tests used a contiguous arrangement of replicated, randomized plots in which inoculum interference between plots obscured the maximum effectiveness of the treatment (8).

In 1972 and 1973, the field performance of RH-124 applied as seed and soil treatments for the control of leaf rust was determined with a similarly replicated and randomized arrangement of isolated plots of Thatcher wheat separated from each other by 30-m borders to reduce inoculum interference. The sprays were applied 23 May 1972 and 29 May 1973 (19 and 35 days after planting, respectively) when natural leaf rust infections were present. In 1972, weather was favorable for leaf rust and a severe epidemic developed on the untreated Thatcher wheat; in 1973 the epidemic was late and only moderately severe. Figure 1 shows the effect of the RH-124 treatments on leaf rust development in comparison to the untreated control in 1972. Effectiveness of RH-124 against leaf rust increased with dose for both methods of application. Control of rust by seed treatment at 140 g/ha was nearly as good as that by the spray application at 469 g/ha.

Control of leaf rust and other foliar diseases by frequent applications of the zinc ion-maneb complex increased yields significantly over the best treatments of RH-124 in both years (Table 3). Treatment with 1,401 g/ha of RH-124 as a spray application in 1972 gave nearly complete control of leaf rust and increased yield 612 kg/ha. The yield from this treatment was not significantly different from that obtained with RH-124 at 469 g/ha as a spray or with 140 g/ha as a seed dressing. Thus, the late increase of leaf rust on the latter two treatments had little effect on yield. The results in 1973 were similar. Control of all foliar diseases by frequent applications of zinc ion-maneb complex resulted in significantly greater yield than all other treatments. Again, control of leaf rust by seed treatment with RH-124 at 140 g/ha was similar to that by spray application at 560 g/ha and both treatments increased yields significantly.

Determination of the ED_{50} values for seed treatment and spray applications from the rust observations made earlier indicated similar differences in the effectiveness of the two methods of treatment. A log-probit plot for seed treatment and for spray application was based on the percentage of rust control by each dose at 70 days after

TABLE 4. Effect on leaf rust on Thatcher wheat of residual activity in the soil from 4-*n*-butyl-1,2,4-triazole (RH-124) one year after application

1973 Treatment	Application Method	Application Amount (g/ha)	1974 Leaf rust severity (%)[a]	1974 Yield (kg/ha)
RH-124	Spray	560	33	2,960 a[b]
RH-124	Spray	280	80	2,413 ab
RH-124	Seed	140	94	1,944 bc
RH-124	Spray	140	94	1,843 bc
RH-124	Seed	70	94	1,805 bc
RH-124	Spray	70	95	1,760 c
Untreated	...	...	95	1,533 c

[a]At 74 days after planting.

[b]Small letters indicate Duncan's multiple range groupings of treatments. Values followed by the same letter do not differ significantly, $P = 0.05$.

TABLE 5. Effectiveness of seed treatment with 4-*n*-butyl-1,2,4-triazole (RH-124) on leaf rust development on cultivars of different rust susceptibility

Cultivar	Treatment	Amount (g/ha)	Rust severity (%) Leaf 64[b]	Leaf 70	Leaf 78	Leaf 83	Stem 89	Yield (kg/ha)
Waldron	Treated control[a]	1,793	0	0	0	0	0	2,999 a[c]
	RH-124	140	0	0	0	0	0	2,596 b
	RH-124	70	0	0	0	0	0	2,468 b
	Untreated	...	0	0	0	0	0	2,394 b
Selkirk	Treated control	1,793	tr	tr	tr	tr	0	2,643 a
	RH-124	140	0	2	30	58	0	2,105 b
	RH-124	70	3	19	70	88	0	1,964 b
	Untreated	...	14	35	91	98	0	1,681 c
Thatcher	Treated control	1,793	0	tr	tr	tr	tr	2,932 a
	RH-124	140	tr	13	30	60	15	1,796 b
	RH-124	70	2	58	94	99	18	1,439 c
	Untreated	...	51	94	99	100	12	1,184 c
Kota	Treated control	1,793	tr	tr	tr	3	tr	2,798 a
	RH-124	140	3	40	85	99	93	572 b
	RH-124	70	39	76	98	100	88	498 b
	Untreated	...	70	90	99	100	88	572 b

[a]Treated controls sprayed with zinc ion-maneb complex at about weekly intervals from tillering to soft dough stages of crop development.

[b]Days after planting.

[c]The small letters indicate Duncan's multiple range groupings of treatments. Values followed by the same letter do not differ significantly at $P = 0.05$.

planting in 1972 and 76 days in 1973 when rust severity in the untreated controls was 95 and 88%, respectively. The ED_{50} values were 70 and 105 g/ha for seed treatment and 294 and 518 g/ha for spray application in 1972 and 1973, respectively; thus, the dosage for seed treatment with RH-124 was four to five times as effective as the dose of a spray application.

Seed treatment tests with RH-124 showed no deleterious effects on emergence or seedling vigor in the field in 1971 and 1972, but stands were reduced in 1973. The 1973 test was planted 24 April when the top 8-cm of soil was very dry and remained dry until 15 mm of rain fell on 29-30 April. The plants in a randomly selected meter of row in each replicate plot were counted at 29 days after planting in the two seed treatments and the untreated control. Stand densities were significantly reduced to 85.2 and 78.5% of the control by seed treatment in the 70 and 140 g/ha treatments, respectively.

Casual observations in early trials indicated that leaf rust was controlled on susceptible wheat replanted in plot areas sprayed with RH-124 the preceding year. To test this further, the four replicate plots for each RH-124 treatment in the 1973 trial were marked for location and replanted with Thatcher wheat in 1974. No additional fungicide was applied. Leaf rust developed earlier and more severely in 1974 than in 1973. At 74 days after planting, wheat on the plot areas treated one year earlier with 560 and 280 g/ha of RH-124 had conspicuously less leaf rust than the remaining plot areas (Table 4). Wheat yields from these plots were significantly greater than those of the untreated controls and the magnitude of yield increases greatly exceeded the increased yields obtained from these treatments in 1973. This difference in yield can be ascribed to the greater destructiveness of the 1974 epidemic compared to the 1973 epidemic. Increased permeation of RH-124 residues through the soil profile over the ensuing year after treatment also may have contributed to more efficient uptake by the plant. The results clearly demonstrate the remarkable persistence of the activity of RH-124 in the soil environment when used at large dosage rates in Minnesota.

The effect of seed treatment with RH-124 on four cultivars of different susceptibility to leaf rust was tested in a series of contiguous plots in 1972. The field reaction of the cultivars to leaf rust were: Waldron, highly resistant; Selkirk, moderately susceptible; Thatcher, susceptible; and Kota, highly susceptible. The four treatments were: (i) untreated control, (ii) treated control sprayed frequently with zinc ion-maneb complex, (iii) seed treatment with 62.5 g RH-124/100 kg, and (iv) seed treatment with 125 g RH-124/100 kg. No leaf rust infection was evident on Waldron throughout the experiment (Table 5). Of the other three, rust increased most slowly on Selkirk, moderately fast on Thatcher, and fastest on Kota. The slight reduction in rust severity at 70 days on Kota in the untreated controls reflects the late emergence and exposure of the flag leaf in this cultivar to inoculum. The rate of leaf rust development on the three cultivars treated with 70 g RH-124/ha was slower than on each of the untreated controls and again rust increased most rapidly on Kota, intermediately on Thatcher, and most slowly on Selkirk. At 140 g RH-124/ha, the rate of increase in leaf rust was considerably greater on Kota than the rate on Selkirk and Thatcher, which had similar rates of increase. The indicated ED_{50} values for disease control by RH-124 at 70 days after planting were 73.6, 84.1, and 133.1 g/ha on Selkirk, Thatcher, and Kota, respectively. Thus, the field results support the greenhouse observations that more RH-124 was required to control leaf rust on Kota than on Thatcher.

The best yields for all cultivars due to control of stem rust and other diseases as well as leaf rust were obtained with frequent applications of the zinc ion-maneb complex (Table 5). Seed treatment had no significant effect on yield in the absence of leaf rust on the highly resistant Waldron. On the moderately susceptible Selkirk, both RH-124 treatments increased yields significantly over the untreated controls, but the difference in yield between the two seed treatments was not significant. On the susceptible Thatcher, yield was increased by the 140 g RH-124/ha treatment significantly over the 70 g/ha treatment and the untreated control. The RH-124 treatments had no effect on the yield of Kota even though leaf rust development was appreciably suppressed; this was due to severe stem rust (Table 5) on this cultivar which negated all effects of leaf rust control by RH-124.

DISCUSSION

Fungicide RH-124 has superior qualities for controlling leaf rust disease of wheat by seed treatment compared to all others tested. The degree of control attained by seed treatment at 70 g RH-124/ha was comparable to control by seed treatment with oxycarboxin at 800-900 g/ha in previous tests (11). The ED_{50} for oxycarboxin was about 117 times that for RH-124 in the protective soil drench assay. Seed treatment with 5-butyl-2-ethylamino-6-hydroxy-4-methyl pyrimidine (ethirimol) at 500-1,000 g/100 kg is reported effective in Europe for control of powdery mildew in spring barley (2). A seedling assay of ethirimol as a protective soil drench against wheat powdery mildew indicated an ED_{50} of 235 μg/pot (10), a dose about 65 times that needed for RH-124 against wheat leaf rust. The criterion of controlling foliar diseases of cereals with a single fungicidal application appears to be met readily by a protective systemic fungicide with a high capacity to remain active in the soil and to maintain an effective dosage in the plant by root absorption. The rough correlation between the results of seedling assays and field performance indicates that the protective soil drench assay gives a good assessment of these characteristics and provides a comparative basis for judging the potential of new compounds.

Control of cereal rusts by seed treatment with effective materials would be economical of material, labor, and energy. The four to fives times greater ED_{50} for RH-124 applied as a spray after rust has appeared in the field compared with application as a seed treatment illustrates the potential of the latter control method to reduce the amounts of fungicide used. Short-range models (3, 4, 5) for predicting cereal rust epidemics, however, would have no value for deciding whether or not to treat the seed. Since systemic fungicides suitable for controlling rust by seed treatment must be persistent, annual usage as insurance against crop loss might result in undesirable accumulation of residues in the environment. Therefore, suitable long-range models for predicting rust epidemics will be required for the most judicious and provident use of this mode of disease control.

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