TESTING FUNGICIDE AND BIOLOGICAL PRODUCTS FOR CONTROL OF GARLIC AND ONION WHITE ROT DISEASE, 1999-2000

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Abstract

Using application rates recommended by the manufacturer, excellent control of garlic white rot was achieved with several rates of seed treatment application of Folicur seed treatment (a systemic), the highest rate of Dividend seed treatment (a systemic), and a high rate Maxim seed treatment (non-systemic). The active ingredients of both Dividend and Folicur are triazole compounds; Folicur was applied at higher rates of active ingredient than was Dividend. With Maxim, white rot occurred just prior to harvest, but most infected bulbs were marketable for dehydration purposes. For full season control, Maxim might be best combined with other products. Excellent control also was achieved with in-furrow applications of Folicur when the total product applied per acre was similar to the amount applied per acre as seed treatment.

All fungicides were more effective against lower populations of the white rot fungus, although certain products and rates were effective against high populations. This confirms previous experience that acceptable fungicidal control is more difficult with larger soil populations of sclerotia of the white rot fungus.

Control of onion white rot was assessed in a trial planted in the spring and harvested in the fall of 2000. It was anticipated that rates of application of triazole products similar to those used for garlic would be required for control of onion white rot, in spite of reported phytotoxicity to onion seedlings. Two alternative application techniques were evaluated: (1) a broader application band was created by mixing fungicide-coated clay granules with onion seed prior to planting the mixture, and (2) flushing in-season band sprays of Folicur downward and around the bulb and upper root system via irrigation, supplemented early in the season by a low-rate seed treatment application. Based on disease levels at harvest, both Folicur and Dividend were promising as clay treatments. Folicur applied over the bed clearly moved with irrigation to provide good control.

Future onion research will refine these methods of application of triazole compounds, and incorporate Maxim as combination seed treatments.

Introduction

The entire sclerotia soil population of *Sclerotium cepivorum* germinate in response to root leakage of germination stimulants. Root infections progress upward on root systems, spreading along the planted row via root contact. Due to extensive root death and bulb decay, infected plants rapidly die once the fungus reaches the stem plate. Lightly infected bulbs near to harvest may pass into fresh onion or garlic markets or may be passed along through garlic seed lots. A few intact but infected bulbs on which the disease has advanced somewhat further may or may not be retained for processing depending on the degree of rot and the harvesting process. Fungicidal control of white rot is difficult, requiring season-long protection in parts of the world where soil temperatures are conducive to prolonged fungal activity. Due to a lack of available controls and the abundant proliferation of the fungus, fields are commonly abandoned following one or more Allium crops infected with white rot.

Prior to 1970, a few very persistent fungicides (e.g., mercury compounds and PCNB) provided partial control of white rot. Since the late 1970's and previous to 1998-1999, few or no fungicides were screened against Allium white rot in the United States, on either onions or garlic. Products still labeled in the United States include Terrachlor (Uniroyal Chem.; a.i. PCNB; for garlic only as a banded spray at planting); Rovral (Rhone-Poulenc; a.i. iprodione; for garlic only as an in-furrow spray at planting), and Botran (Gowan Co.; a.i. DCNA; eastern OR & WA, western ID only; for onions, banded pre-seeding; for garlic in-furrow spray at planting). None of these fungicides currently are being used on full-season Allium crops because of insufficient or inconsistent control. Benlate (DuPont; a.i. benomyl) is labeled as a garlic seed treatment for control of penicillium seed piece decay, and provides partial control of white rot for a limited duration, but is ineffective for season-long control. In other countries, Sumislex (a.i. procymidone) has provided fair-to-good control of white rot, depending on the disease pressure. More recently, Folicur (Bayer; a.i. tebuconazole) has provided fair-to-excellent control in Mexico, Australia, and New Zealand, depending on disease pressure and rate and method of application. The work reported here was initiated as a result of reported successes in those countries.

An additional incentive to test Folicur was that this product proved effective against garlic rust in California, and an emergency label was granted for this use in 1998. Having a rust tolerance for Folicur should expedite labeling of Folicur for white rot, even though the methods and rates of application might differ.

Fumigants have been used to lower soil populations of white rot and reduce the risk of disease spread, but have not provided sufficient control. This includes even methyl bromide, which may lower sclerotial populations by 98-99 percent. More recently, germination stimulants have achieved 98-99 percent population reduction when used at appropriate rates and methods of application. Such stimulants may be registered soon in the United States (United Agri Products; a.i. diallyl disulfide), and research-in-progress has shown that comparable population reduction of sclerotial populations may be achieved with commercially available dehydrated garlic powder as the source of germination stimulants, and likely at similar cost to the UAP product, which is derived from petroleum. These stimulants are of interest because of their relatively high efficacy and low cost compared to methyl bromide. As indicated above, fungicides provide poorer control of white rot when sclerotial populations are high. A recent concept has been to pre-treat fields with germination stimulants in years prior to planting Alliums, and then apply the more effective fungicides such as Folicur. Our trials in 1999-2000 tested the efficacy of fungicides against a high and low population of *S. cepivorum* to evaluate this concept.

In addition to direct economic control of white rot with fungicides on a specific crop, sclerotial population reduction is a goal of fungicide use. Temporary control can be misleading and sustained control elusive; if even a few Allium plants are allowed to develop white rot, which might be economically acceptable in the short term, the sclerotial population may increase, making future control more difficult. On the other hand, season-long control might lead to near-eradication if Alliums are repeatedly protected with a superior fungicide. Thus, full product evaluation must be based not only on control achieved, but also on the increase or decrease on the resultant sclerotial population.

This report addresses the second trial year. In 1998-1999, Folicur and Dividend (Syngenta, a.i. difenconazole) performed well, but the garlic stand was reduced by an untimely winter freeze. In 1999-2000 we again tested fungicides in two adjacent trials against both a moderately low and a moderately high soil population of *S. cepivorum.* Our long-term goal was to identify and refine treatments that provide full control of white rot under low-to-moderate infestations of *S. cepivorum*, and possibly under high infestation.

In addition, we tested fungicides in 2000 on spring-seeded, fall-harvested onions against a moderate soil population of *S. cepivorum.* The onion trial was considered preliminary for testing methods of Folicur and Dividend application that might circumvent seedling sensitivity to these fungicides but still provide adequate disease control. These approaches included distributing fungicides more widely around the seed by coating them on granular materials planted with seed, and spraying fungicides believed to be somewhat mobile in water directly over the seedbed prior to irrigation. The former idea was adapted from the Folicur label for onions in Tasmania, and the latter idea was suggested by Mary Ruth McDonald with the University of Guelph based on preliminary data in Canada.

Garlic Trial, 1999-2000, Madras, Oregon

Methods

The field was naturally infested only at trace levels that contributed very little to the disease levels experienced. The overall area was divided into two trials. In September 1999, one trial was infested uniformly with 4-5 sclerotia/L soil, and the other trial with 10-15 sclerotia/L soil, using heavily infested soil recovered during the spring of 1999 from around previously rotted onion plants in a nearby onion seed field. This added inoculum was tilled to 15 cm (6 inches). Based on previous experience, it was expected that 50-75 percent bulb infection or plant death would occur in untreated plots of the low infestation area, and more than 95 percent plant infection or death would occur in untreated plots of the high infestation area. Each plot consisted of a single 40-ft bed section. All treatments were randomized within six blocks.

The area was tilled, fertilized with 400 lb/acre 16-16-16 and prebedded. Beds were shaped and planting furrows opened with a planter provided by Basic Vegetable Products. Virus-free California Early garlic cloves, cracked but not hot water treated, were sized within a narrow range (approx. 2,300 lb/acre) and planted 16 cloves per bed ft on 36-inch centers. Following various treatments and hand planting, hoes were used to cover seed 2 inches deep, using soil from both sides of the planting furrow.

Fungicide products were applied either on seed (labeled ST), or in the planting furrow (labeled IF or in-furrow), or in the case of biological materials by direction of the company providing the products.

Products and methods of application are shown in Table 1. Seed treatments in water were sprayed onto cloves rotating in glass gallon jars 2 days prior to planting. The amount of water used was sufficient to coat seed fully but remain on the inside of the jar. In-furrow applications were sprayed with 50-gal/acre water in a 4-inch band in-furrow opened by a garlic planter.

The biological product LiquiComp/Ceres required special handling. According to the manufacturer, this two-part bacterial mixture typically would be applied with irrigation water through the season. In our case, plot bed sections were prewatered with a sprinkling can across the entire 36-inch bed (5 gal/40 ft) section. Two-thirds of the combined product immediately was sprayed across the bed, and the garlic was planted and covered by hand. One-third of the material was sprayed across top of bed (18-20 inches), and additional water (5 gal/40 ft) was sprinkled over the bed. Product application and seed planting of this treatment was conducted within an hour of sprinkler irrigation. We agreed to reapply over the top of plot bed sections just prior to each irrigation.

Table 1. Products and treatment types and rates used in a white rot of garlic fungicide trial near Madras, Oregon, 1999-2000.

In furrow	Seed treatment
Rovral 50 WP (4.3 lb/acre)	Folicur 3.6F (0.25 g a.i./kg seed)
	Folicur 3.6F (0.5 g a.i./kg seed)
Folicur 3.6F (1L/ha)	Folicur 3.6F (0.75 g a.i./kg seed)
Folicur 3.6F (1.5 L/ha)	
Folicur 3.6F (2 L/ha)	Dividend 3FS (0.5 oz/100 lb seed)
	Dividend 3FS (0.75 oz/100 lb seed)
Maxim 4FS (0.5 lb a.i./acre)	Dividend 3FS (1 oz/100 lb seed)
Quadris 2.08SC (0.8 oz ai/1,000 ft row)	Maxim 4FS (0.08 oz/100 lb seed)
	Maxim 4FS (0.16 oz/100 lb seed)
Fluazinam (0.4 oz/1,000 ft row)	
	Dividend + Maxim (0.5 oz + 0.08/100 lb seed)
LiquiComp + Ceres (8 gal/acre + 4 gal/acre)	Dividend + Maxim (0.75 oz + 0.08/100 lb seed)

Results

Garlic was well rooted during the late fall of 1999, but no top growth developed until mid-February through mid-March 2000. The winter of 1999-2000 was mild.

Stand. Emergence was deteimined on March 16, 2000 (Fig. 1). The apparent differences in stand between the two trials cannot be compared statistically. The higher stand in untreated check plots at higher infestation levels was probably a random phenomenon. Within the moderately low infested trial, stands were higher in all treated plots compared to the untreated check, although Fluazinam and LiquiComp/Ceres treatments did not statistically differ from the control ($p < 0.05$). Within the moderately high infested trial, stands were comparable ($p < 0.05$) to the untreated control for Rovral, higher rates of Folicur ST, the highest rate of Dividend ST, Maxim IF, Quadris IF, and Fluazinam IF. In both trials, the best stands were achieved with the high rate of Dividend + Maxim ST, both rates of Maxim ST, all rates of Dividend ST, and the lowest rate of Folicur ST. The lower garlic stands at higher rates of Folicur application suggest that garlic may have some sensitivity to elevated Folicur levels, as reported for onions.

White Rot Progress. White rot progress was rated periodically during the season. White rot symptoms were observed on a few plants by the end of March. Irrigation began mid-April. The first application of LiquiComp/Ceres was applied at that time. By May, white rot symptoms were noticeable in both untreated and LiquiComp/Ceres-treated plots in both trials. In early May LiquiComp/Ceres was no longer applied because white rot seemed worse in plots treated with that product. During May, white rot symptoms appeared in plots of all treatments in which yields were low at harvest. A plot tour was held on June 1, 2000. At that time in the moderately low infested trial, little or no white rot symptoms appeared on foliage in plots treated at planting with all rates of Folicur ST, the two higher rates of Folicur IF, all rates of Dividend ST, both rates of Maxim ST, and both rates of Dividend + Maxim ST. The lowest rate of Folicur IF manifested some late-developing white rot on June 1. In the moderately high infested trial, little or no white rot symptoms were observed on plants treated with all rates of Folicur ST, the highest rate of Folicur IF, the middle rate of Dividend ST, the higher rate of Maxim ST, and the higher rate of Dividend + Maxim ST.

Nearly all plant loss following emergence was attributed to white rot. Five plants infected with botrytis were removed from the trial area during 2000. A foliage application of Rovral was applied during early May to suppress botrytis activity.

The final irrigation was on July 1. Garlic was undercut on July 11, and bulbs were hand pulled, cleaned of dirt, and rated for infection by *S. cepivorum* between July 11 and 14. Bulbs that were either smaller than 3 cm or considered too diseased to be retained in normal harvest processes were discarded. Bulbs that were determined to be infected on the stem plate or bulb but which were considered intact enough to be retained by normal harvest practices for a processing crop were graded as "Symptomatic." Bulbs without signs or symptoms were graded as "Asymptomatic." Garlic was left in the field, and harvest weights were determined on July 20 when foliage was relatively dry.

Symptomatic and asymptomatic bulbs were counted and weighed separately, but only the combined weight is reported. Treatment means for the number of harvestable bulbs are shown in Figure 2 and means for harvest weight are shown in Figure 3 for both the moderately low and the moderately high-infested trials.

Treatment Comparisons At Harvest. As per Figures 2 and 3, Rovral, Maxim IF, Quadris IF, Fluazinam IF, and LiquiComp/Ceres provided little or insufficient protectiori against white rot at the rates and methods of application used, at either level of infestation. These treatments are not discussed further.

Moderately low infested trial. All three application rates of Folicur ST provided superior disease control, bulb size and harvestable yield. Nevertheless, there were differences among these three rates of application. More symptomatic bulbs occurred at harvest with the lowest rate of application compared to the higher rates, but total bulbs and yield were highest for this treatment except for the performance of the high rate of Maxim in this trial. This may relate to higher initial stand for the lowest rate of Folicur ST. In fact, this treatment (0.25 g a.i./kg seed) of Folicur was the second-most superior treatment in this trial.

The two higher application rates of in furrow Folicur performed nearly as well as Folicur seed treatments, but the lower rate was inferior. The highest rate of Dividend ST was close to the better Folicur treatments, and mean yields were not separable statistically ($p < 0.05$). The higher rate of Dividend + Maxim ST also performed very well and was comparable to Folicur treatments.

Although the lower rate of Maxim ST performed reasonably well, the higher rate (0.15 oz/100 lb seed) performed extremely well. No white rot symptoms were present on June 1, although some white rot was present on bulbs at harvest for this treatment. This suggests that Maxim may have degraded at the very end of the season. Nevertheless, the highest total harvestable bulbs and harvest weight were recorded for this treatment.

Moderately high infested trial. In this trial, the number of harvestable bulbs and harvest weights were lower than for the moderately low infested trial. There were fewer superior treatments with respect to bulb infection and harvest weight. Again, the lower rate of Folicur ST was the best of the three seed treatment rates. This further suggests that the higher rates of Folicur ST may be directly detrimental to garlic. This was the only treatment in this trial that is comparable to yields in the moderately low infested trial. The highest rate of Folicur IF performed as well as the higher rates of Folicur seed treatment. Dividend ST rates performed only fairly, although the middle rate performed reasonably well. The higher rate of Maxim ST performed as well as Folicur. Neither rate of Dividend + Maxim performed as well as the better Folicur treatments or the higher rate of Maxim ST.

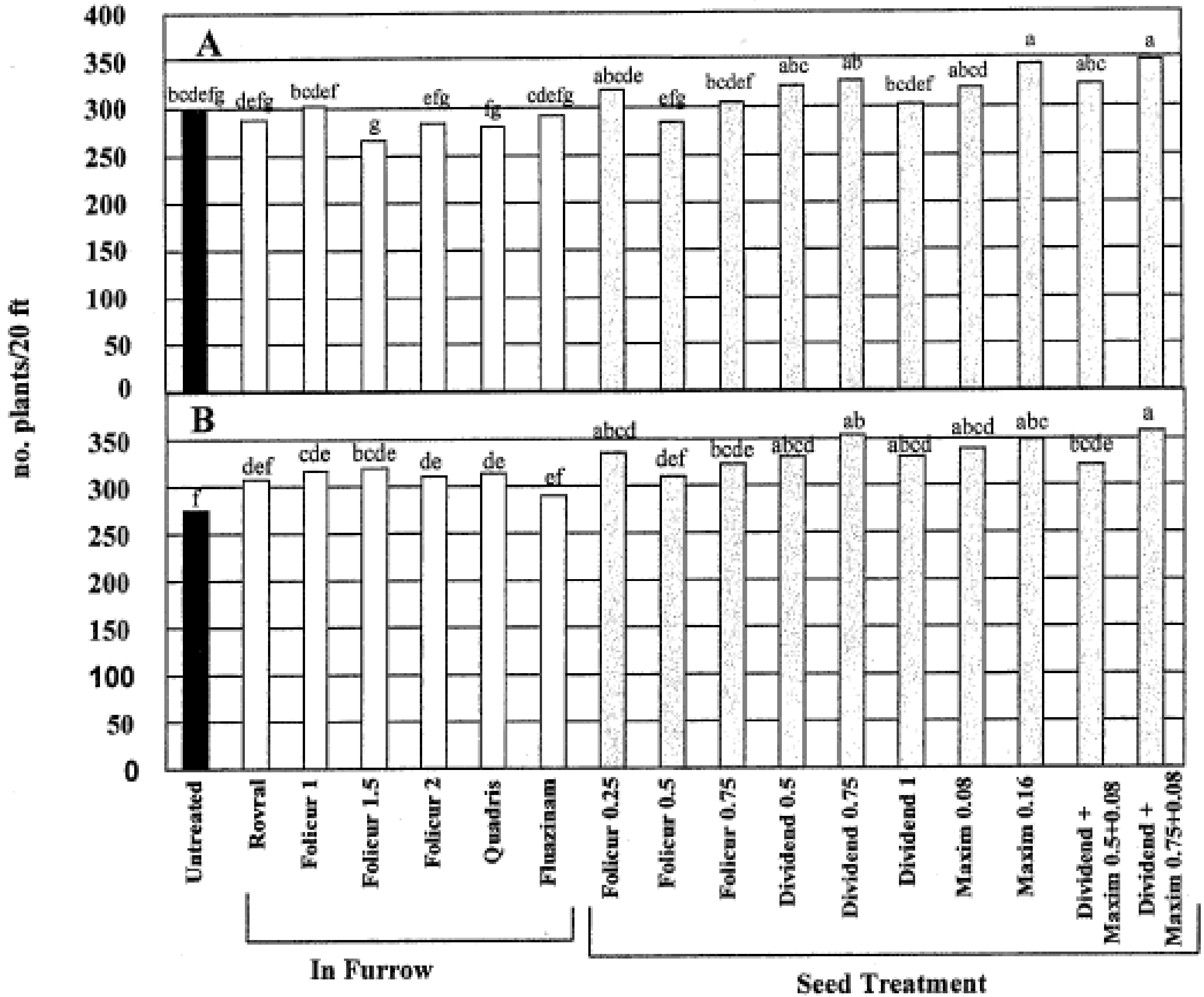

Figure 1. Effect of products on garlic stand in high (A) and low (B) white rot infestation trials, 2000. Means labeled with the same letter are not significantly different according to Fisher's protected least significant difference (LSD) test ($P \leq 0.05$).

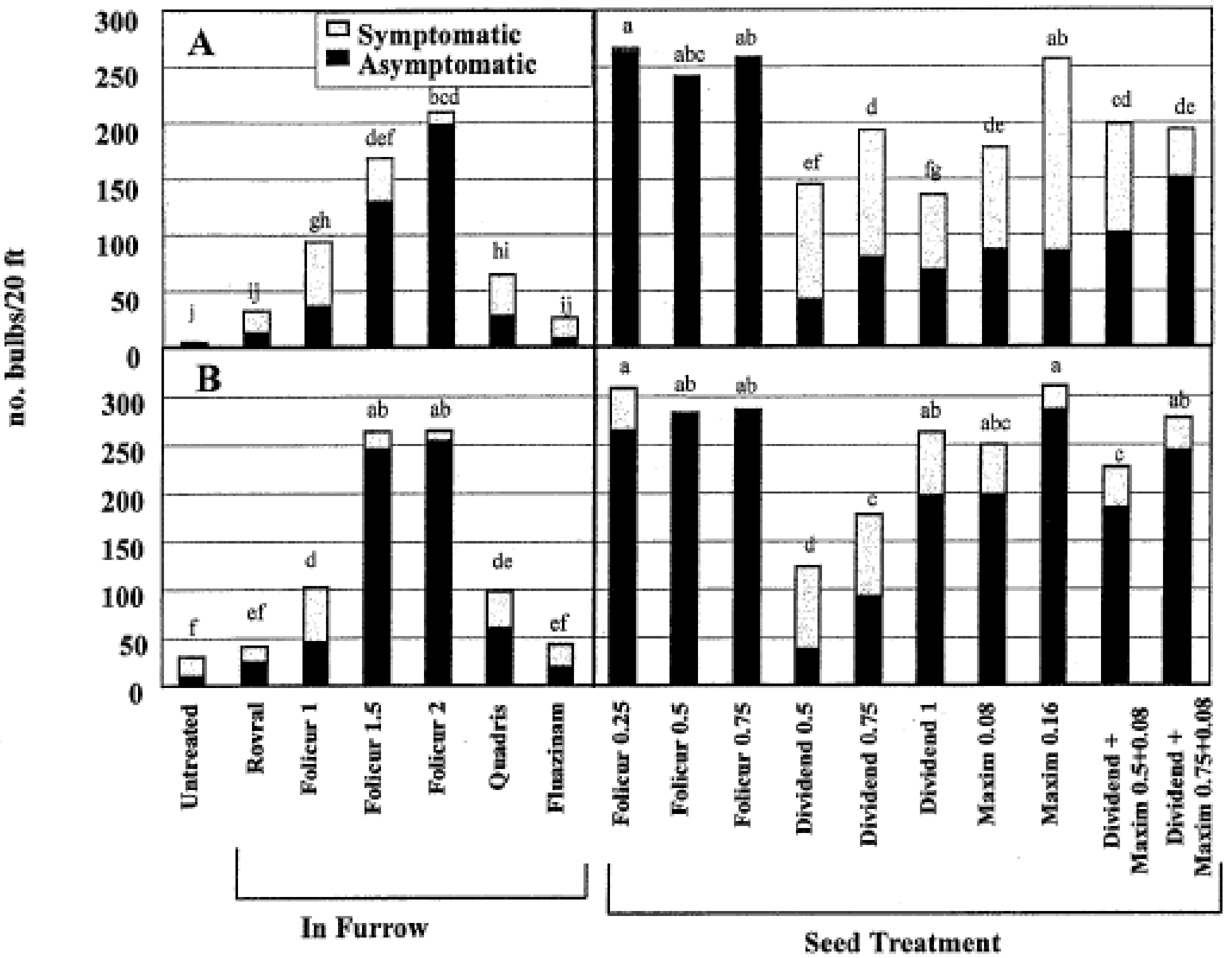

Figure 2. Effect of products on number of garlic bulbs in high (A) and low (B) white rot infestation trials, 2000. Means labeled with the same letter are not significantly different according to Fisher's protected least significant difference (LSD) test ($P \leq 0.05$).

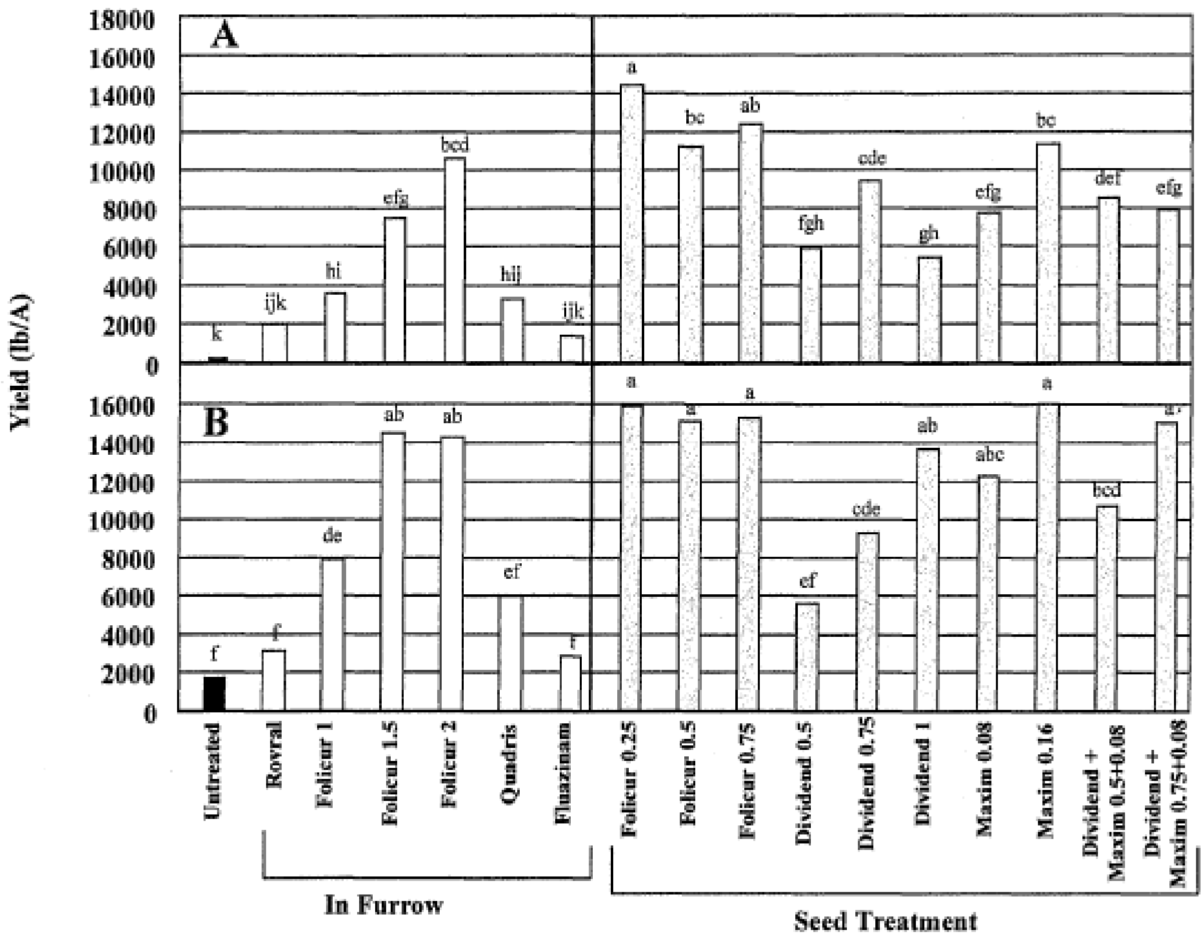

Figure 3. Effect of products on garlic yield from high (A) and low (B) white rot infestation trials, 2000. Means labeled with the same letter are not significantly different according to Fisher's protected least significant difference test ($P \leq 0.05$).

Discussion

Based on pre-planting inoculum densities of *S. cepivorum,* about 75 and 95 percent of plants were expected to be either killed or infected by harvest in the moderately low and moderately high infested trials, respectively. However, based on initial stand counts and ignoring preemergence losses, approximately 97 percent of the untreated garlic was killed or infected at the stem plate by harvest in both trials. Such high incidence likely was related to the mild winter of 1999-2000, which extended the active season for *S. cepivorum.*

A careful study of Figure 3, however, reveals that the impact of white rot was worse in the moderately high infested trial, as measured by lower bulb weights. Fewer treatments performed well through season's end. Undoubtedly, even with the best treatments, root systems were more highly diseased in the moderately high infested trial, which led to somewhat higher bulb infection and reduced bulb size even on asymptomatic bulbs.

The superior treatment used in both trials was Folicur 3.6F applied to seed at 0.25 g a.i./kg seed. Higher rates of Folicur seed treatment may have decreased the rate of bulb infection but also reduced stands, numbers of harvestable bulbs, and harvest weight, although these differences were not statistically significant. Perhaps garlic, like onions, is sensitive to Folicur. In Tasmania, Jason Dennis (Fieldfresh, personal communication) indicated that in every white rot trial in which Folicur was included, onion stands were reduced. Onion roots and foliage may be adversely affected, but Folicur nevertheless provides the best control of all products tested.

Dividend 3FS did not perform as well as during 1998-1999, but still provided reasonable control of white rot. Novartis wished us only to test Dividend as a seed treatment, and did not wish us to use rates higher than 1 oz/100 lb seed. The active ingredients in Folicur (tebuconazole) and Dividend (difenconazole) are related but not identical triazole compounds, and a comparison of actual rates of active ingredients are included in Table 2. Triazoles are systemic in plants, and are somewhat mobile in soil, so seed treatment with Folicur or Dividend may allow for slightly more protection than restriction to the surface of the clove and developing bulb.

Maxim 4FS applied as a seed treatment, especially at 0.16 oz/100 lb seed, provided impressive white rot control, especially considering, that the active ingredient, fludioxonil, is not mobile in soil. Nevertheless, Maxim control did not persist through the end of the season at either infestation level, even though it was the superior performer in the moderately low infested trial. While perhaps insufficient by itself when soil populations of *S. cepivorum* are high, Maxim might greatly extend the level of control when combined with an appropriate rate of Folicur or Dividend. In fact this is clear from the Dividend + Maxim seed treatments for both 1998-1999 and 1999-2000.

In the Madras trial, Folicur applied in-furrow did not provide the same level of control as Folicur seed treatments, except at the highest rate of application, but only the highest rates of in-furrow application were equivalent to seed treatment rates as shown by active ingredient per hectare conversions (Table 2).

We worry that seed-treatment application based on garlic seed weight might result in high variability in actual applied material per plant and per unit area: garlic cloves commonly are sized before planting to create more uniform growth in the crop.

Table 2. A comparison of rates of application of active ingredients of products found effective against garlic white rot in 1999-2000 in Madras Oregon.

Product name	Active ingredient	Amount applied as in-furrow spray	Grams a.i./kg seed	Oz product/ 100 lb seed	Grams a.i./ha'
Folicur 3.6F	Tebuconazole		0.25	0.89	638
			0.50	1.78	1,276
			0.75	2.67	1,913
Folicur 3.5F	Tebuconazole	1.0 L/ha			430
		1.5 L/ha			645
		2.0 L/ha			860
Dividend 3FS	Difenconazole		0.12	0.50	298
			0.17	0.75	449
			0.23	1.00	597
Maxim 4FS	Fludioxonil		0.025	0.08	1.8
			0.050	0.16	3.6

'Assumes a seeding rate of 2,250 lb garlic cloves/acre (1,022.7 kg seed/ha) for seed treatments, and all products are applied within the seeding line as either seed treatments or in-furrow sprays at planting time.

Seed sizes may vary from less than 1,500 lb/acre (small seed) to over 3,500 lb/acre (large seed) to achieve the same plant population. Our estimates suggest nearly a 2.5-fold difference in product applied per plant for cloves at the extremes of this range, although most seed lots may fall within a narrower range, perhaps 2,200-2,800 lb/acre. Further discussions with pesticide manufacturers will occur to resolve the optimal way to express the amount of applied product.

Thus, per gram active ingredient per hectare, the lowest seed treatment rate of Folicur used was comparable to the middle rate of Folicur applied in-furrow. At the moderately low infestation these treatments were comparable in performance, although the seed treatment was superior to the in-furrow treatment in the moderately high infestation. This suggests that concentrating the product near the seed confers a benefit, which could be as simple as limiting the dilution of products, which have some water solubility, but this is speculative.

The comparison does suggest that we may be choosing rates of application for Dividend that are too low, if difenconazole is comparable in activity with tebuconazole.

Onion Trial, 2000, Madras Oregon

Methods

An onion trial was located near the garlic trials reported above. Soil was uniformly infested to 15 cm (6 inches) with about 5 sclerotia/L of soil on April 5, 2000, in a similar manner and with identical inoculum as used in the garlic trial. This inoculum density was anticipated to result in about 70 percent plant loss or infected bulbs at harvest based on past experience with spring-planted onions in Tulelake, California. This is a lower estimate than for over-wintered onions or garlic because the effective white rot season is shortened for spring-planted onions, as few onion roots are present for several weeks following seeding. For similar reasons, little preemergence loss from white rot is expected with direct-seeded onions.

Onions were grown as a spring-planted and fall-harvested commercial bulb crop. However, because of the equipment available, beds and plant density simulated an onion , seed field planting. An onion variety grown for dehydrating was used. In most ways, this onion crop could not be directly compared with normal onion crops, but as a preliminary trial this was considered reasonable.

Along with sclerotia, 500 lb/acre of 16-16-16 fertilizer was incorporated on April 5, 2000. Onions were planted on April 21. The variety was a numbered, white dehydration type from Rogers Foods, 94 percent germ and 107,333 seeds/lb. The planter was calibrated to plant 4 lb seed/acre, adjusted for germination, or about 29 seeds per ft in two lines along the top of each bed. All seed was thoroughly mixed with a commercial granular, inert clay soil amendment (Turface). The granules of this product were 1-3 times the size of the onion seed. The seed opening plates were adjusted to a number 30 hole size, which dispensed 44.8 lb/acre Turface along with the 4.0-lb seed/acre. Planting depth was roughly 0.25 inch, and seed and Turface were scattered horizontally across about 0.75 inch per planted line. Bed tops were 18 inches wide, with onion lines spaced 9 inches apart. Turface and/or seed were treated as described below, and each plot consisted of 40-ft-long beds x 2 beds wide. The planter had four seed hoppers, and two hoppers were used to plant the two lines on each bed. Extra Turface and seed were used to fill the hopper for each 40-ft plot, to ensure proper seed flow through the planter. After each plot, hoppers were cleaned of residual Turface and seed.

The trial consisted of 16 treatments organized into 5 randomized blocks. After emergence, 5 ft were removed from each end of each plot to create implanted alleys and to remove any irregular planting at the beginning and end of each 50-ft planting run. Thus, after alley removal, plots were 30 ft long.

Onion treatments are shown in Table 3. Treatments were chosen for the onion trial before garlic trial data were available, which could have influenced our choice of products and application. For seed treatments, fungicide was sprayed into a rotating glass jar containing onion seed, using enough water to coat seed but not wet the inside of the jar. The rates shown for seed treatments are product applied per 100,000 seeds.

Table 3. Fungicide products, methods of treatment and rates of application for onion white rot trial near Madras, Oregon, 2000.

Seed treatment[b]	Turface clay treatment'	Seed treatment + spray[b]
Folicur 3.6F (1.0 a.i./100,000 seeds)	Folicur 3.6F (0.5 L/ha)	Folicur 3.6F (1.0 ai/100,000 seed) + early season pre-irrigation band spray (1.0 L/ha per 48 gal/acre water)[d]
	Folicur 3.6F (1.0 L/ha)	
Dividend 3FS (1.0 a.i./100,000 seeds)	Folicur 3.6F (1.5 L/ha)	Folicur seed trt + early and mid season band sprays (total 1.5 L/ha Folicur sprayed/season)[d]
	Folicur 3.6F (2.0 L/ha)	
Dividend 3FS + Maxim 4FS (1.0 a.i./100,000 seed + 0.08 oz/100 lb seed)	Dividend 3FS (1.0 L/ha)	Folicur seed trt + early and mid season band sprays (total 1 L/h Folicur sprayed/season)[d]
	Dividend 3FS (1.5 L/ha)	Folicur seed trt + early, mid and mid-to-late full bed sprays (total 3 L/h Folicur sprayed per season)[e]
	Maxim 4FS (2.9 oz/acre)	Folicur seed trt + Vapam (3 gal/acre) full bed spray[f]

Not listed is the untreated control, which included untreated seed mixed with untreated Turface clay prior to planting.
[b]Includes untreated Turface clay mixed with fungicide-treated seed prior to planting.
[c]Turface clay was treated with fungicide and mixed with untreated seed prior to planting.
[d]Sprayed over top of bed (18 inches wide). Early season spray June 5. Mid-season spray July 3.
'Sprayed over top of bed (36 inches wide). Mid-to-late season July 27.
Vapam applied June 16 during first 30 min of an irrigation set.

For treated Turface clay particles, a similar rotating glass jar procedure was used. Rates per acre shown for Turface treatments are product per full acre, even though material was distributed only in the seed line. Some experimental treatments contained only seed treatment, some contained only treated Turface, and some contained independently treated seed and Turface. Seed and Turface were treated several days prior to planting, and were thoroughly air dried prior to planting. Neither seed nor Turface treatment seemed to affect flow rates during planting. Additional treatments included in-season band sprays just prior to irrigations. Rates per acre shown are for product per full acre, even though material was applied in a band. On April 21, Dacthal (7 lb/acre) and Ramrod (5 pt/acre) were applied to the trial area, and irrigation began on April 23. Irrigation was intermittent and the weather remained cool for 2-3 wk. Trial emergence was slow. Partial emergence was evident on May 8-12, and full emergence was evident by May 15-19. Following full emergence, onions were irrigated as needed though mid-September. Furadan (1 pt/acre in 21 gal/acre water, unregistered use) was applied to seedlings on May 25 for control of maggots (none seen) and thrips, and again July 24 for thrips.

On October 2, the onions were undercut, lifted, and most dirt removed from roots. Onions were left on the soil surface for foliage to dry. Rain fell periodically during October, and prolonged the drying period and final harvest measurements. This extended the activity of *S. cepivorum.* Bulbs were graded for infection on bulb or stem plate in mid-October. Final grading for size and harvest weight determination was on November 13-14. Noninfected bulbs less than 1.2 inches (3 cm) in diameter were discarded. Larger noninfected bulbs were separated into two size classes and weighed separately: bulbs 1.2-2.0 inches (3.0-5.0 cm) in diameter, and bulbs greater than 2.0 inches (5 cm) in diameter.

Results

For seasonal sprays, the onions on June 5 had 2 true leaves. Onion growth and development were not clearly delineated for sprays on June 16, July 3, and July 27. Erratic phytotoxicity (plant death) mixed with undamaged plants was evident within a week following the Vapam treatment. White rot symptoms were first noticed on June 20 in untreated checks and plots treated with the low rate of Dividend applied with Turface.

Plant stand. Seeding was less uniform than desired; there appeared to be erratic flow from hoppers. Stand was assessed on June 15. No stand differences were attributed to white rot, as the onion seedling root system was not substantial enough to make contact with sclerotia of *S. cepivorum* at the populations present. Mean stands ranged from 485 to 726 seedlings per plot, with an average of 669.3 (21.3 seedlings/bed ft) and standard deviation of 57.1 (1.9 seedlings/bed ft) The widest variation (485-726) occurred for the set of treatments 12-16 that were treated identically through stand evaluation. Thus we cannot determine whether stand was mildly affected by products, but it seems unlikely that stand was greatly affected by applied products. In future, another type of planter may be needed, and seed and granules (if such treatments are continued) should be dispensed via separate mechanisms.

Stand declined during the season because of various factors. White rot was found in every plot, although very little was found in plots where 300 or more noninfected and sizeable bulbs were harvested (see below). Some plants were lost to hand weeding during the season, and to heavy thrip damage in July. There were at least two moisture stress episodes in the trial area due to coordination problems with our cooperator-farmer and high winds that precluded irrigation at times. We estimate that the original stand of 21.3 plants per bed ft more realistically declined to about 17 plants per bed ft by mid-season, ignoring white rot attrition.

Additionally, some plants remained small and formed small bulbs. This is attributed to root and foliage damage from various undetermined sources. Many small bulbs failed to make our harvest grade.

Harvest. The mean number of bulbs per size class per 30-ft plot appears in Figure 4. The mean harvest weight per acre is shown in Figure 5, including data separated by harvest size class. We excluded from these harvest yields all bulbs that were infected with white rot at the stem plate, or bulb, and all noninfected bulbs less than 1 2 inches (3 cm) in diameter. We caution against making strong comparisons with normal commercial yields.

Harvest data were not adjusted for differences in stand. Even in the best treatments, we harvested fewer plants than our original stands. The best treatment yielded 13.1 harvested plants per bed ft. This is 61.5 percent of the original average stand of 21.3 plants per bed ft. Using our estimated adjusted stand of 17 plants per bed ft suggested above, we harvested 77.1 percent of the stand from this best treatment. Of course, the attrition in these figures includes both white rot losses and small noninfected bulbs. The small bulbs are the most difficult to understand, as it is not clear whether these were small from mid-season stresses, from white rot root damage, or from adverse fungicide effects on roots. Some of these uncertainties will need to be worked out in future testing, with a more uniform planting.

In the following analysis, we ignore the unresolved stand issues, and assume all yield differences at harvest are due to white rot. There were clear differences among treatments with respect to the number of bulbs harvested, the distribution of these bulbs within the size classes shown, and the overall harvest weight (Figs 4 and 5). The poorest yield was in the untreated control, which averaged only 109 noninfected bulbs per 30 ft at harvest, or 3.6 bulbs per bed ft. This corresponds to 78.9-83.1 percent loss to white rot during the season, depending on the stand count estimate used. This was a little higher than our anticipated 70 percent plant loss from white rot based on initial inoculum density estimates. This difference can be attributed to delayed harvest along with continued disease ingress in cool, moist periods between lifting and grading.

Several treatments yielded only slightly better than the untreated control, including Folicur and Dividend applied only as seed treatments. Dividend + Maxim seed treatment and the Vapam treatment fared only slightly better. These results were not significantly different and were not unexpected.

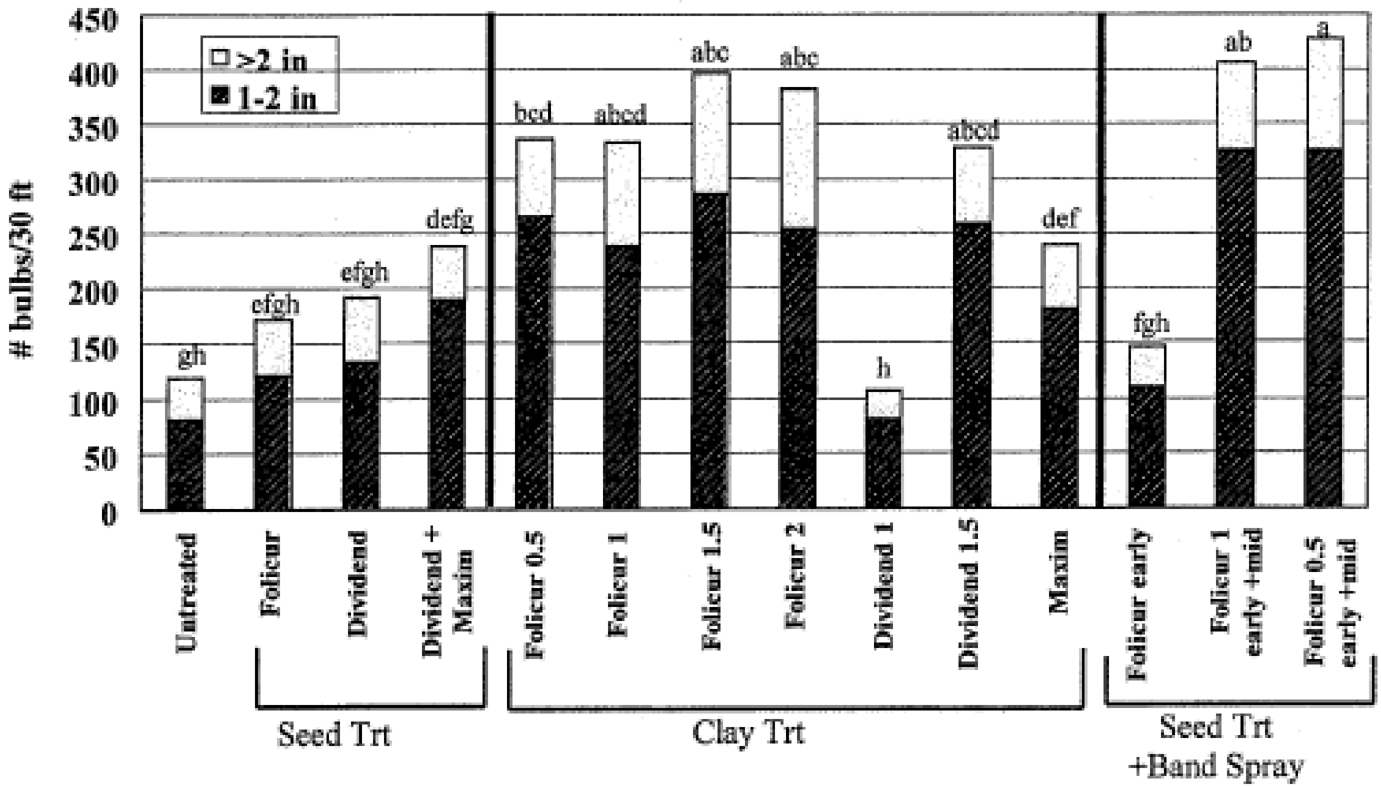

Figure 4. Effect of products on number of onion bulbs with diameter of 1-2 inches or more than 2 inches grown in a white rot trial, 2000. Means labeled with the same letter are not significantly different according to Fisher's protected least significant difference test ($P \leq 0.05$).

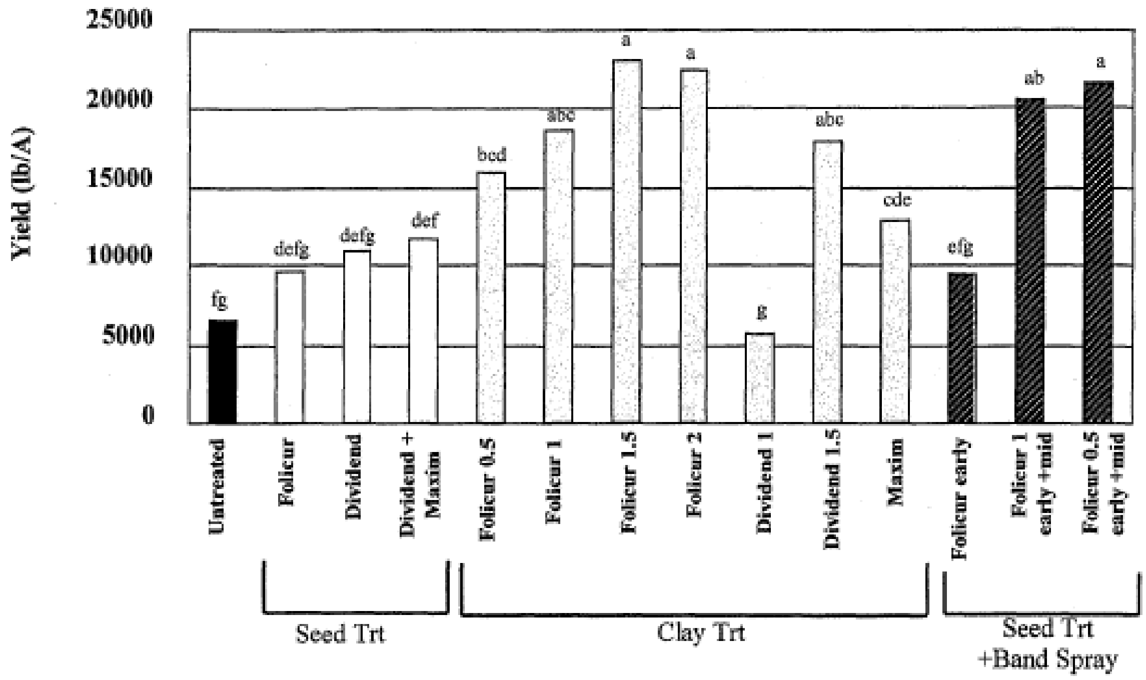

Figure 5. Effect of products on onion yield grown in a white rot trial, 2000. Means followed by the same letter are not significantly different according to Fisher's protected least significant difference (LSD) test ($P \leq 0.05$).

Among Turface clay treatments, Maxim and the low rate of Dividend performed similarly to the untreated control and were not significantly different.

Other Turface clay treatments performed significantly better than the untreated control. Increasing rates of Folicur applied in this manner yielded an increasing number of non-infected bulbs, and a proportional shift from smaller to larger bulbs. The higher rate of Dividend applied with clay performed as well as all rates of Folicur. With more uniform flow and placement of a pelletized or granulated formulation, this performance might improve.

Discussion

Combinations of Folicur seed treatment with in-season banded sprays performed well where Folicur was banded twice during the season. We reasoned that the seed treatment would provide short-term protection until root systems were well established. We hoped that Folicur, applied over the top of the bed prior to irrigations, would move down to protect the bulb and upper root system from white rot control. Our timing of application was based simply on guesswork. Future work could include variations on timing and rates of application. We suspect that much of the late-occurring white rot that developed in these treatments might have been excluded with a banded application applied in mid to late August.

We had expected good disease control from the broadcast application of Folicur over the whole bed (not just the bed top), applied three times and at somewhat higher rates of application. However, this treatment was only moderately successful, probably because insufficient product was focused near to bulbs themselves.

In future, we might concentrate band sprays even more tightly near the planting line; it is very possible that our bed-top banded sprays were less focused than might be optimal

We are encouraged by the substantial improvements in white rot control using fungicides applied both on clay and banded over the top of the bed. We can improve the way we plant and manage the onions, and we can improve the precision of application of granulated or pelletized products by using better machinery than was used in 2000. By trying different timing, rates, and bandwidths, we expect that banded in-season sprays might work much better than demonstrated in this trial. In summary, we are greatly encouraged that white rot control of onions might be achieved comparable to our relative success with garlic. Onions do, however, pose a more technical challenge of application than garlic.

Acknowledgement

Financial support was received from the Nevada Garlic and Onion Board and the American Dehydrated Onion and Garlic Association, and in-kind contributions from various growers and companies.