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Aerial Application Trial for Control of Southern Cone Rust in a Slash Pine Seed Orchard Using Triadimefon

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A nonreplicated field trial was conducted in a slash pine seed orchard in north-central Florida to evaluate the efficacy of aerially applied triadimefon fungicide for control of southern cone rust caused by Cronartium strobilinum. *A single, late January application of fungicide was apparently ineffective, but trees receiving an additional application 16 days later had significantly fewer rust-infected conelets. Clonal variation with respect to disease susceptibility and apparent genotype-treatment interactions were observed. The potential of triadimefon-based cone rust control is discussed.* Tree Planters' Notes 47(4)126–131; 1996.

Southern cone rust—caused by the fungus *Cronartium strobilinum* (Arth.) Hedgc. & Hahn—sporadically causes serious losses of first-year female strobili on slash (*Pinus elliottii* Engelm. var. *elliottii*) and longleaf (*P. palustris* Mill.) pines in the Atlantic and Gulf Coastal Plains of the deep southern United States. Infected conelets typically swell rapidly (figure 1a), abort, and drop from the tree by mid to late summer, but some hypertrophied red-brown to brown, somewhat shriveled "mummies" may cling to trees for longer periods (Goolsby and others 1972; Hedgcock and Hahn 1922; Hepting and Matthews 1970; Maloy and Matthews 1960; Matthews 1964; Miller 1987). In some years, cone (and subsequently seed) losses directly attributable to southern cone rust infections have ranged from 20 to nearly 100% in certain areas (Goolsby and others 1972; Hedgcock and Hahn 1922; Hepting and Matthews 1970; Maloy and Matthews 1960). Fatzinger and others (1992) reported losses of not less than 24% in a slash pine seed orchard in north Florida in 1980. Losses in another slash pine seed orchard in north central Florida were very high in 1993, 1994, and 1995 (estimated >75% in 1995 by Barnard and others, unpublished field observations). Responding to a survey questionnaire, 8 of 12 seed orchard managers in Florida, southern Georgia, and southern Alabama estimated their 1995 losses of first-year slash pine cones to be in excess of 50% (Barnard, unpublished data).

a

b

Figure 1—*Symptoms and signs of southern cone rust on slash pine: Infected (lower left) and disease-free first-year conelets (**a**). Infected first-year cones displaying profuse powdery masses of yellow-orange aeciospores (**b**).*

Control of southern cone rust has been reported with appropriately timed spray applications of ferbam fungicides (Hepting and Matthews 1970; Lightle 1959; Maloy and Matthews 1960; Matthews 1964). However, due to the non-systemic, prophylactic mode of action of ferbam, effective control requires repeated applications, perhaps at 5-day intervals for a period of some 25 to 30 days, commencing as soon as female strobili emerge from their bud scales and continuing until pollination has ended. Accordingly, the overall efficacy of ferbam-based control programs may be less than adequate due to weather conditions and costs of applications (especially if applications are aerial).

Since the early 1980's, triadimefon fungicide (Bayleton®, Bayer Corporation) has become the industry standard for controlling fusiform rust caused by *Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *fusiforme* (Hedgc. & N. Hunt) Burdsall & G. Snow, a close relative of *C. strobilinum*, in southern pine nurseries (Carey and Kelley 1993; Kelley 1985; Kelley and Runion 1991; Powers 1984; Rowan 1982; Snow and others 1979). Triadimefon's mode of action is systemic, and to some extent eradicant, as opposed to preventive only; triadimefon controls or eradicates some preexistent infections and prevents new infections. In addition, single low rate applications (for example, 280 g ai/hectare or 4 oz ai/ac) of triadimefon provide effective control of fusiform rust in pine seedlings for up to 3 to 4 weeks.

Accordingly, we designed this study to determine if aerially applied triadimefon fungicide would be effective in controlling southern cone rust in pine seed orchards. If effective, this approach could reduce the number of fungicide applications required for adequate disease control and provide orchard managers flexibility with respect to timing of spray applications.

Materials and Methods

Trial layout and fungicide application. In 1996, we established fungicide trials in 4 seed orchards in Florida. Due to the erratic nature of the disease, southern cone rust did not occur in 3 orchards but did occur at the Florida Division of Forestry's Withlacoochee Seed Orchard near Brooksville, FL. Accordingly, we are able to report results from only of 1 of the 4 seed orchards.

In the Withlacoochee Seed Orchard, we selected a 20-ha (~ 50 ac) block of slash pine and identified 2 (5-row) zones for fungicide application (figure 2). Application zones were chosen to avoid orchard block edges, minimize disturbance(s) to a bordering landowner, and provide a reasonable buffer (9 rows = about 82 m, or 270 ft) between zones. The 4 corner trees in each of the 5-row zones were marked with flagging in their crowns, and each spray zone corner was marked on the ground to facilitate pilot identification/location. The size of the orchard and limitations of flight patterns precluded replication (figure 2).

The first application of triadimefon (Bayer Corporation's Bayleton® 50% DF) was applied to both application zones on January 29. On February 14, a second application was applied to 1 zone only. The result was a 5-row zone of trees receiving a single application of triadimefon (1/29, 1×) and another 5-row zone receiving 2 applications (1/29 and 2/14, 2×). The 2 zones were separated by a 9-row (about 82 m, or 270 ft) unsprayed buffer zone (figure 2).

Both fungicide applications were delivered by fixed-wing aircraft calibrated to deliver 19 L of spray/ha (= 5 gal/ac) with a droplet size of volume median diameter (VMD) = 350 μm. On both application dates, the respective target zones were double flown, making the actual application 38 L of spray/ha (= 10 gal/ac). The spray mixture consisted of 227 g (½ lb) of Bayleton 50 DF and 0.24 L (½ pint) of Agri-Dex® nonionic spray adjuvant/38 L (10 gal) of total spray/ha. Thus, about 280 g (10 oz) ai of triadimefon fungicide was applied per hectare per application on the 2 test zones.

Data collection. Incidence of southern cone rust was assessed between April 29 and May 2. Total cone counts and the number of cones exhibiting symptoms and/or signs of cone rust infection (for example, distinctive hypertrophy of cone scales or conelets, orange discoloration, and/or the presence of aecial pustules or aeciospores of *C. strobilinum*; figure 1) were determined on the eastern half of the crown on each selected sample tree. Counts were made from a bucket truck, and as each cone was counted, it was sprayed with fluorescent paint to prevent inadvertent recounts.

Primary sample trees were selected in the 2 sprayed zones from trees within the interior 3 rows of each zone (figure 2). Control trees were selected in the largest unsprayed zone from among trees within 4 adjacent rows that were at least 9 rows (about 82 m, or 270 ft) distant from the nearest sprayed zone (triadimefon 1×). Sample trees were selected on the basis of ramet availability for individual clones within the designated sampling zones. Three ramets per clone per area were desired, but some clones only provided 2, or in some cases, 1. The total sample consisted of 57 trees (3 clones with at least 3 ramets/clone/zone, 3 clones with 2 ramets/clone/zone, and 3 clones with only 1 ramet/clone/zone). Two additional clones were sampled, but these clones (308 and 402) were represented in only single orchard zones (table 1). Additionally, and in a similar manner, we determined the proportions of cones with cone rust on a single clone (403) for which we could find at least 2 ramets in each of

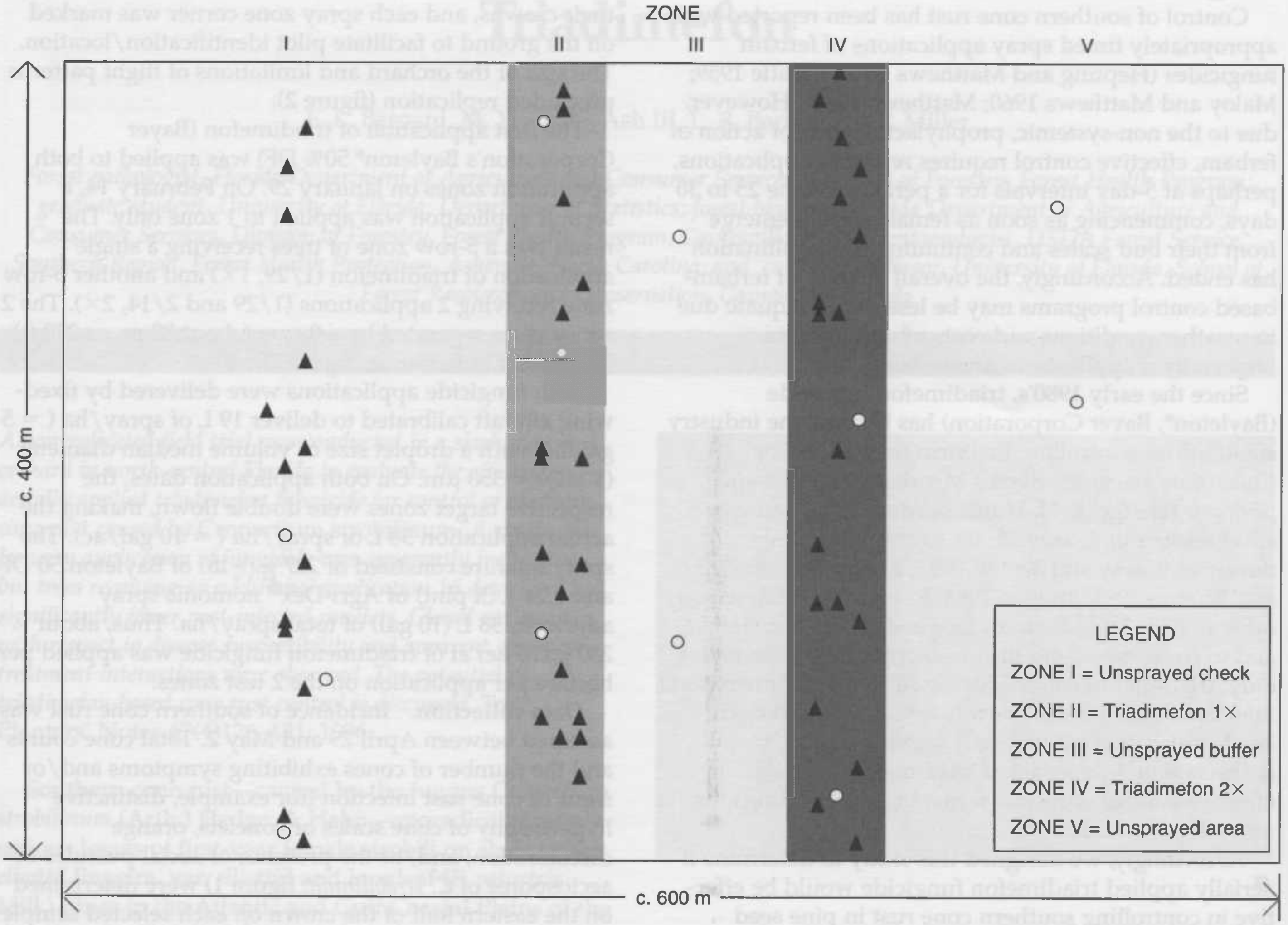

Figure 2—Layout of a field trial evaluating aerially applied triadimefon fungicide (Bayleton® 50% DF) for control of southern cone rust in a slash pine seed orchard; Florida Division of Forestry's Withlacoochee Seed Orchard, Brooksville, FL, 1996. Solid triangles and clear circles represent individual sample trees with the circles indicating individual ramets of clone 403 sampled across all 5 orchard zones.

the 5 zones across the orchard (figure 2). This supplemental sample was taken to evaluate the possibility of a disease gradient occurring across the orchard, possibly confounding analysis of treatment effects in zones I (control), II (triadimefon 1×), and IV (triadimefon 2×) (table 1 and figure 2).

Data analysis. Because this study involved unreplicated treatment plots, there are limitations to the inferences that can be drawn from the data collected. Nonetheless, statistical analyses were used as an aid in evaluating the validity of observed differences in cone rust levels between orchard zones and/or treatments. Data were subjected to logit regression analysis because the response variable was dichotomous, that is, the cones either had or did not have rust. The statistics package SPLUS® (Statistical Sciences, Inc.) was employed for data processing. In the first analysis, only the data from zones I (control), II (triadimefon 1×), and IV (triadimefon 2×) were analyzed. Clones 308, 402, and 306 were not included in the analysis. Clones 308 and 402 clones could not be included because they were represented only in single orchard zones (table 1). Clone 306 was omitted as a probable anomaly (outlier) because it was the only clone of 9 represented that showed a dramatic "increase" in rust infection in zone II (triadimefon 1×) over zone I (control), a difference based on only single measurements (that is, single trees) in each of the 2 zones (table 1). Each of the other 8 remaining clones showed essentially no difference in rust infection levels between zones I (control) and II (triadimefon 1×) (table 1). A second analysis, of the supplemental sample, was performed using only the data from clone 403 across all 5 orchard zones (table 1 and figure 2).

Table 1—*Total number of cones evaluated and percentage of cones infected (in parentheses) by Cronartium strobilinum by clone, ramet, and seed orchard zone (treatment)*

Clone & ramet	Zone I (controls)	Zone II (triadimefon 1×)	Zone III (buffer, nonsprayed)	Zone IV (triadimefon 2×)	Zone V (buffer,nonsprayed)
2					
1	82 (4.9%)	205 (11.7%)	—	110 (4.6%)	—
2	130 (13.9%)	63 (14.3%)	—	75 (12.0%)	—
3	150 (15.3%)	133 (9.0%)	—	99 (6.1%)	—
7					
1	68 (7.3%)	42 (21.4%)	—	117 (11.1%)	—
2	179 (15.9%)	77 (7.8%)	—	79 (16.5%)	—
3	150 (11.3%)	99 (8.1%)	—	110 (16.4%)	—
4	75 (2.7%)	—	—	—	—
403*					
1	192 (12.0%)	225 (4.0%)	123 (11.4%)	55 (1.8%)	98 (30.6%)
2	109 (10.1%)	197 (13.2%)	148 (6.1%)	120 (1.7%)	206 (4.8%)
3	75 (17.3%)	189 (16.9%)	—	239 (8.4%)	—
19					
1	255 (23.5%)	176 (22.7%)	—	92 (15.2%)	—
2	63 (14.3%)	92 (16.3%)	—	76 (10.5%)	—
27					
1	37 (51.4%)	71 (43.7%)	—	175 (54.3%)	—
2	130 (40.0%)	134 (41.0%)	—	65 (56.9%)	—
304					
1	194 (28.9%)	150 (29.3%)	—	107 (16.8%)	—
2	89 (24.7%)	149 (18.8%)	—	62 (9.7%)	—
11					
1	42 (38.1%)	38 (31.6%)	—	33 (21.2%)	—
2	—	23 (34.8%)	—	—	—
3	—	32 (21.9%)	—	—	—
26					
1	108 (15.7%)	80 (17.5%)	—	91 (11.0)	—
306					
1	163 (4.9%)	168 (18.4%)	—	75 (5.3%)	—
308					
1	91 (18.7%)	—	—	—	—
402					
1	—	—	—	57 (7.0%)	—
2	—	—	—	44 (11.4%)	—
3	—	—	—	44 (9.1%)	—

* Clone 403 values were included in the analysis of zones I (control), II (triadimefon 1×), and IV (triadimefon 2×)(figure 3). In addition, values for this clone for all 5 zones (treatments) were analyzed alone (figure 4).

Results and Discussion

Our data document considerable clonal variation, not only with respect to the incidence of cone rust within specific clones (and therefore susceptibility/resistance to infection), but also with respect to clonal responses to our triadimefon applications as well (table 1). For example, average cone rust infection within individual clones represented by at least 2 ramets ranged from 9.2 (clone 7) to 45.7% (clone 27). Similar clonal variation has been observed previously by Fatzinger and others (personal communication). They observed average clonal infection ranging from 3.5 to 36.2% in a 1980 outbreak of cone rust in a slash pine seed orchard in north Florida. Our analyses suggest possible genotype by treatment and/or zone interactions (not separable due to the unreplicated nature of the trial). For example, clones 2, 403, 19, 304, 11, and 26 exhibited significantly less ($P = 0.05$) rust infection in zone IV (triadimefon 2×) than in either zone I (control) or zone II (triadimefon 1×). In contrast, clones 7 and 27 exhibited more (NS) rust infection in zone IV than in zones I and 11. Average rust infection levels in zones I (control) and II (triadimefon 1×) did not differ significantly (figures 3 and 4). Also, our analysis of infection levels in clone 403 confirmed that only in zone IV (triadimefon 2×) did cone rust infection levels differ significantly from those of zone I (control) at $P = 0.05$ (figure 4). Indeed, rust levels for clone 403 in zone V (unsprayed area), not differing significantly from zones

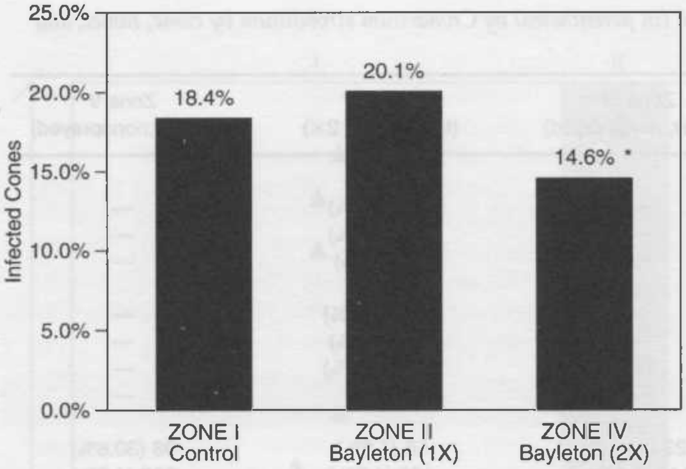

Figure 3—*Mean incidence of southern cone rust infection (% cones infected) in a slash pine seed orchard treated with aerially applied triadimefon (Bayleton® 50% DF). Values/bars annotated with an asterisk differ significantly from those of zone I (control) at* P = *0.05.*

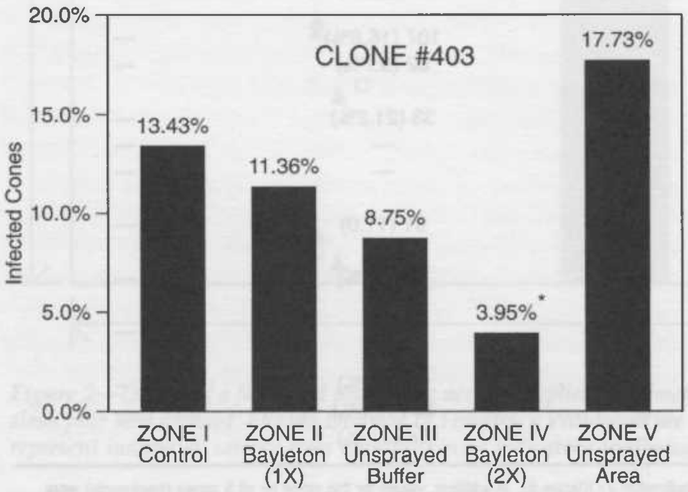

Figure 4— *Mean incidence of southern cone rust infection (% cones infected) in a single clone of slash pine across 5 seed orchard zones treated or untreated with aerially applied triadimefon (Bayleton® 50% DF). Values/bars annotated with an asterisk differ significantly from those of zone I (control) at* P = *0.05*

I (control), II (triadimefon 1×), and III (buffer), argue against there being a disease gradient across the seed orchard (figure 4).

Altogether, our data suggest that our double fungicide application (triadimefon 2×) may have reduced the level of cone rust infection in this trial. However, due to the unreplicated nature of our trial, and the consequent confounding of zone (orchard position) with treatment, unequivocal statements with respect to treatment efficacy are premature. Further, should the observed differences in cone rust levels in fact be a function of our fungicide treatments, our data would not enable us to determine whether the effect of the triadimefon 2× treatment was due to the repeated application or simply better timing of the second application. In this respect, we are inclined to prefer the latter explanation as rust levels in our single application zone (triadimefon 1×) did not differ significantly from those in the control zone. Regardless, we are intrigued by our initial results and the possibilities. We believe further trials are in order.

Benefits and costs? Economic justification for aerial triadimefon applications for control of southern cone rust must be determined almost on a case-by-case basis. Cone/seed production per hectare of seed orchard, the value of seed, costs of chemicals (fungicide and adjuvants), costs of aerial application contracts, disease pressure, and level of disease reduction are all factors to be considered. Assuming that our trial results provide a reasonable basis for expected control of southern cone rust (that is, a direct 20% reduction in disease occurrence), calculating the cost effectiveness of an aerial triadimefon spray program will depend largely on the anticipated level of disease incidence, a factor for which we currently have no reliable predictor(s).

For example, assuming 22 kg of seed produced/ha (20 lb/ac), $110/kg of seed ($50/lb), $136 for chemicals/ha ($55/ac) [inclusive; , based on 1,121 g (1 lb) of triadimefon plus adjuvant total for both applications], $74/ha ($30/ac) for total application costs (2 flights), and a disease incidence and control efficacy equivalent to those on our trial, control costs would be $210/ha ($85/ac) and the value of seed saved would be $88/ha ($37/ac); a net loss of $122/ha ($48/ac) for "control". If, however, a single application of triadimefon provided the same level of control, then control costs would still exceed the value of seed saved by $17/ha ($5.50/ac) . For comparison, if disease pressure were greater (for example, 50% cone/seed losses without control) and all other factors remained the same, a double application would result in a net gain of $32 worth of seed/ha ($15/ac), whereas a single application would provide a net gain of $137 worth of seed/ha ($57.50/ac).

Notwithstanding the above, application costs for triadimefon may, in effect, be "reduced" due to the fact that application schedules are essentially coincident with those recommended (Dixon and others 1991) for insecticidal control of slash pine flower thrips—*Gnophothrips fuscus* (Morgan)—and tank mixes of fungicide and insecticide are feasible. In our trial, applications were scheduled to coincide with insecticide applications and laboratory tests for tank mix compatibility using Bayer's Bayleton 50 DF and Riverside/Terra Corporation's Malathion 5®, showed no evidence of incompatibility (unpublished data). Further, the use of triadimefon for rust control in slash pine seed orchards may provide additional indirect benefits by reducing activity of the south coastal coneworm—*Dioryctria ebeli* Mutuura and Munroe—which preferentially attacks rust-infected conelets. If unchecked, populations of this insect build up in rust-infected conelets, with subsequent generations attacking second-year cones, thus causing even greater losses (Dixon and others 1991; Merkel 1958; Miller 1987).

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