PROTECTION OF BLISTER RUST-RESISTANT WESTERN WHITE PINE CONES FROM INSECT DAMAGE WITH PERMETHRIN AND FENVALERATE

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ABSTRACT: Production of seed from blister rust-resistant western white pine in northern Idaho has been severely reduced by the mountain pine cone beetle and the fir coneworm. In 1981 and 1984, insecticide treatments to control these insects to maximize seed production were evaluated in Idaho. At one test site, Sandpoint, 0.03 pct. permethrin significantly reduced loss of cones to the mountain pine cone beetle; however, 0.06 pct. permethrin was more cost effective. At the other test site, Moscow, the fir coneworm infested 46.6 pct. of the untreated cones, significantly more than 13.6 pct. in the single application of 0.025 pct. fenvalerate. A double application of fenvalerate increased seed yield significantly from 31.3 to 56.0 seeds/cone when compared to the untreated check. A third application of fenvalerate was apparently unnecessary.

INTRODUCTION

Western white pine (Pinus monticola Douglas) is one of the more valuable species in the northern Rocky Mountains. However, the introduction of the pathogenic fungus Cronartium ribicola Fischer to the United States from Europe in the early 1900's nearly eliminated western white pine (Haig and others 1941). To preserve this species for timber, the USDA Forest Service started a breeding program to select for resistance to this disease (Bingham 1983).

Recently, the production of blister rust-resistant seed from western white pine in seed orchards has been severely reduced in Idaho because of periodic infestations of the mountain pine cone beetle Conophthorus ponderosae Hopkins (=C. monticolae) at the Sandpoint (Idaho) Seed Orchard (Jenkins 1982; Shea and others 1984) and the fir coneworm Dioryctria abietivorella (Groté) at the Moscow (Idaho) Arboretum (Haverty and others 1985; Shea 1985). The western conifer seed bug Leptoglossus occidentalis Heidemann and the lodgepole cone moth Eucosma rescissoriana Heinrich have been observed in the Moscow Arboretum; however, we have not yet associated any significant damage with these insects.

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The life history of C. ponderosae with respect to the phenology of white pine cones has been described (Williamson and others 1966). White pine cones require about 15 months to reach maturity (Owens and Molder 1977). In early spring, as second-year cones begin to elongate, adult cone beetles emerge from overwintering sites within old cones. Female beetles initiate attack and bore into the young cones. They rapidly girdle the axis of the cone, thereby severing the conductive tissue and killing the cone. Adult females may attack up to four cones, depositing a maximum of 100 eggs. Normally, however, only 4 to 8 adults emerge from an infested cone (Jenkins 1982). The rapid attack and subsequent mortality before the cones are half-grown make successful control difficult (Furniss and Carolin 1977).

The fir coneworm is a transcontinental species that attacks cones of many conifer species. It also mines in the buds, shoots, and trunks of conifers. Its life history is variable and not well known. Apparently, in Moscow, larvae pupate in cocoons on the ground in August and September and emerge as moths in June. Eggs are laid soon after emergence, and larvae feed from June to August or September. Larvae mine the inside of cones but also crawl on the outside throughout cone development (Furniss and Carolin 1977; Hedlin and others 1980). Feeding throughout the cone development period could necessitate multiple insecticide applications.

This paper reports the results of experiments conducted in Idaho in 1981 and 1984 to evaluate single and multiple, high-volume ground applications of two insecticides--permethrin and fenvalerate--for protection of cones of blister rust-resistant western white pine. Our objective was to protect the cone crop from the major pest at two test sites (Sandpoint and Moscow) that attack cones during the second year of cone development.

MATERIALS AND METHODS

The insecticides selected were chosen on the basis of human safety and efficacy against C. ponderosae (Haverty and Wood 1981) or Dioryctria spp. and Leptoglossus corculus (Say)(Nord and others 1984).

Sandpoint-Conophthorus

The study site was the Sandpoint Seed Orchard. In 1981, the 17.3-acre (7.0-ha) orchard contained 800 grafts of 21-year-old western white pine. Trees ranged in height from approximately 15 to 45 ft (5 to 15 m). Permethrin (Pounce) was sprayed in April 1981. Ten trees between 20 and 45 ft (7 and 15 m) tall were randomly assigned to each of seven treatments. Ramets were from three clones with similar susceptibility to C. ponderosae attack (Jenkins 1982). Trees next to a previously selected tree or in a previously designated buffer zone were not used. The seven treatments consisted of an untreated check, and 0.03, 0.06 and 0.12 pct. permethrin in water applied once, the same concentrations applied again 14 days later. Trees were sprayed between 0500 and 0930 within a 2-day period with a Bean hydraulic sprayer mounted on a trailer. The sprayer was calibrated to deliver approximately 5 gallons (18.9 liters) per tree within 48 seconds. Mixing was done just before application and all trees within a treatment were treated consecutively. The order of treatment within any morning was random.

Twenty-one days following the second application and after all attacks had occurred, all cones on all trees were inspected and counted as infested vs. noninfested. Because timing is critical to protection of the cone crop, five screened cages, each with 50 infested cones collected in the orchard or from the surrounding area, were placed throughout the orchard. Spraying began 1 day after the first beetle emerged. Treatments were analyzed by pairwise tests of differences with a 2 x 2 contingency table (infested vs. noninfested vs. treatment) and a chi-square statistic at α = 0.01.

Previous work in the orchard indicated a high probability that the beetle population would be low in 1981 (Jenkins 1982). Because of concern that insufficient attacks would not allow an adequate test of the insecticide, beetles were collected elsewhere and placed throughout the orchard. Infested cones containing overwintering beetles were collected in and around Sandpoint, and held until the trees were treated. Immediately after spraying, 15 infested cones were placed under test trees (including checks) to ensure adequate attack.

Moscow-Dioryctria

The Moscow seed orchard is rectangular in shape and covers approximately 12 acres (4.9 ha) on the western edge of the University of Idaho campus. Our study area comprised the northeast quarter of the seed orchard and had approximately 340 P. monticola of cone-bearing age. Only trees with an initial cone crop of $\geq$ 20 second-year cones were used. The remainder of the seed orchard was separated from the study area by a draw at least 60 ft (20 m) wide. To protect the majority of the cone crop in the seed orchard from seed-destroying insects, this area was treated three times (once each in May, June, and July) with fenvalerate applied aerially at a rate of 0.75 lb AI/acre (0.84 kg AI/ha) delivered in 10 gallons of water (93.5 liter/ha). The draw served as a clearly visible buffer to guide the helicopter pilot so that the insecticide would not drift into the study area. Insecticide drift was monitored during each spray application with water-sensitive spray deposit cards. No drift was detected, and the study area was assumed to be free of insecticidal contamination from the adjacent control operation.

Fenvalerate (Pydrin Insecticide 2.4 EC) was diluted in water to a concentration of 0.025 pct. (wt/wt) and applied with a trailer-mounted sprayer. Mixing was done just before application. The tank mixture was applied to near the point of runoff with an FMC Bean hydraulic pumper using a hand-operated gun. Trees were sprayed in the early morning and late evening when wind was minimal to avoid contamination of adjacent trees. Between applications, spray equipment was cleaned and rinsed with Nutra Sol.

Treatments were done on three dates in 1984: 9 May, 13 June, and 18 July. Since exact phenologies of the three insect pests were unknown, the application schedules were modified after the procedure of Nord and others (1984) to be approximately 30 days apart. Pheromone traps baited with candidate E. recissoriana pheromone were distributed diagonally across the orchard at about 6 ft (2 m) above ground in trees, and inspected every other day for the appearance of adult males. The first application coincided with the first E. recissoriana catch.

The experiment was executed with a completely randomized design. Four treatments were compared: an untreated check, a single application (9 May), a double application (9 May and 13 June), and a triple application (9 May, 13 June, and 18 July). Each insecticide treatment was randomly assigned to 12 trees; 22 trees were randomly assigned to the untreated check. We selected trees spaced sufficiently apart to avoid contamination. As a result, we occasionally replaced randomly selected trees if they were too tall or too close to adjacent trees.

Before the first insecticide application, all cones on the treatment and check trees were examined and counted. Before each subsequent insecticide application, all cones were reexamined for obvious insect damage or the presence of L. occidentalis adults or nymphs. Cones with insect damage or insects present were flagged, numbered, and left on the tree. A final observation was made on 21 and 22 August. Previously infested and newly infested cones were collected and bagged separately and returned to the laboratory in Berkeley, California. The remaining cones were picked from 22 to 25 August. Cones were counted, put in separate burlap bags, and air dried.

The seed was extracted at the USDA Forest Service Coeur D'Alene Nursery, Idaho. Uncleaned seed lots from each tree were put in plastic bags and mailed to Berkeley. All seed lots were carefully cleaned. Eight groups of 100 seeds from each tree were weighed and placed in envelopes. The remaining seeds were also weighed. Seeds per tree were estimated based on the mean weight of the 800 seeds for that tree. In lots with less than 800 seeds, all seeds were counted.

The eight envelopes with 100 seeds per envelope were taped to an 8 by 10 inch (20 by 25 cm) sheet of paper and radiographed to determine percentages of empty seed, seed with a viable embryo, or seed damaged by L. occidentalis or some unknown cause. Individually collected cones damaged by insects were air dried and the seed were extracted by shaking. Seeds from each cone were counted and radiographed. Data from infested and noninfested cones were combined and used to calculate cone and seed yields for each tree.

The response variables were number of cones harvested per tree, proportion of cones infested, and number of seed per cone. Analysis of variance and analysis of covariance with the number of cones per tree as the covariate were used to detect differences between treatments at the $\alpha = 0.05$ level. Bonferroni's t-statistic (Miller 1980) was used to compare means and to maintain a $\alpha = 0.05$ for all comparisons (Jones 1984). Percentages of filled, empty, or damaged seed were also computed.

RESULTS AND DISCUSSION

Sandpoint-Conophthorus

Beetles began to emerge on 18 April, 1981, and trees were first sprayed on 19 and 20 April. Trees were resprayed on 2 May. No statistically significant difference occurred in the mean number of cones per tree by treatment (table 1). All permethrin treatments had levels of infested cones that were significantly different from the untreated controls. Additional pairwise comparisons revealed the following statistically significant relationships in percent loss of cones: 0.03 pct. once < 0.06 pct. once < 0.12 pct. once = 0.03 pct. twice < 0.06 pct. twice < 0.12 pct. twice (table 1). Percent loss of cones ranged from 75.8 pct. in the untreated controls to 1.7 pct. in the 0.12 pct. double treatment (table 1).

Moscow-Dioryctria

No statistically significant differences occurred between treatments in the number of cones harvested per tree (table 2). However, the final number of cones varied considerably between trees, and ranged from 11 to 186. Dioryctria abietivorella infested 46.6 pct. of the cones in the untreated check. This was significantly more than in any of the insecticide treatments. The proportion of infested cones among insecticide treatments did not differ significantly (table 2). Furthermore, we found no statistically significant relationship between the number of cones on a tree and the proportion of the cones which were infested.

Observations in the seed orchard in previous years indicated the presence of three potential pests of cones and seeds. Although E. recissoriana was present and captured in pheromone traps during 1984, we saw little evidence of damage by this species. Leptoglossus occidentalis also had been abundant during past years, but very few insects were observed during our test. Little, if any, cone damage was observed until 16 July 1984 (fig. 1). All damage was apparently caused by D. abietivorella. In July, less than 4.0 pct. of the cones receiving the single application of 0.025 pct. fenvalerate were damaged by coneworms, whereas ca. 25 pct. of the untreated cones were infested. By August, the proportion of damaged cones on untreated trees increased to 46.6 pct. while only 13.6 pct. of the cones on trees sprayed once and 4.1 and 5.1 pct. of the cones on trees receiving two and three sprays, respectively, were damaged (fig. 1; table 2).

Double or triple applications of 0.025 pct. fenvalerate increased seed yield significantly compared to the untreated check, that is, from 31.3 to 56.0 or 50.0 seeds/cone. The 95 pct. confidence interval for the difference in mean seeds/cone between two applications of fenvalerate and the untreated check is 24.7±15.3. In other words, we are 95 pct. confident that this treatment increased seed production by at least 9.4 seeds/cone (an increase of 30.0 pct.), and possibly as much as 40.0 seeds/cone (an increase of 127.8 pct.).

Analysis of covariance showed no effect of cone crop size on number of seed per cone during 1984. All treatments also had approximately the same proportion of filled, empty, and damaged seed (table 2). This undoubtedly results from little or no feeding by L. occidentalis and random oviposition behavior of D. abietivorella.

The high cost of establishing seed orchards and the fact that these orchards are the primary, if not sole, source of resistant western white pine seed make the develoment of effective insecticide treatments an important research effort. The

Table 1.--Infested and noninfested western white pine cones, by permethrin treatment

Treatment	Cones infested	Cones noninfested	Mean cones/tree[1]	% loss of cones[1]
0.03% once	254	234	48.8a	52.0b
0.06% once	203	379	58.2a	34.8c
0.12% once	105	353	45.8a	22.9d
0.03% twice	131	478	60.9a	21.5d
0.06% twice	66	600	66.6a	9.9e
0.12% twice	8	488	45.6a	1.7f
Untreated	547	174	72.1a	75.8a

[1]Means in a column followed by the same letter are not significantly different at the $\alpha = 0.01$ level.

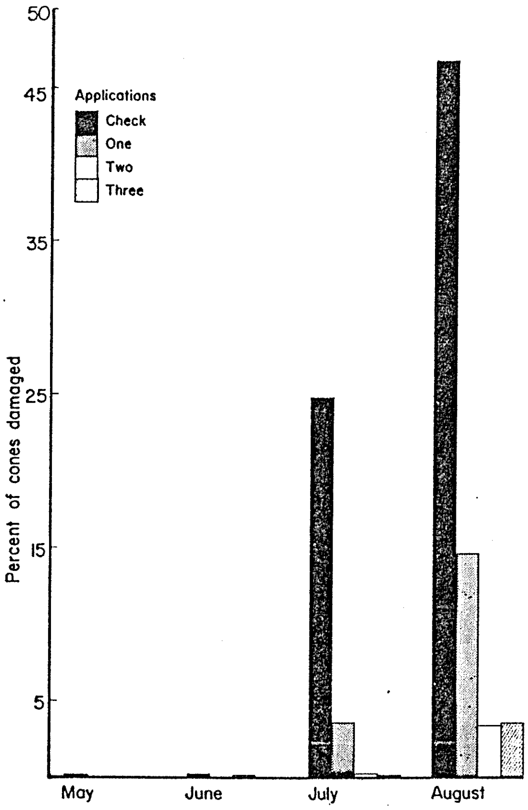

Figure 1.--Percent of western white pine cones damaged by Dioryctria abietivorella. Single applications of 0.025% fenvalerate were applied on 9 May, 13 June and 18 July.

mountain pine cone beetle C. ponderosae was the only insect of concern in the Sandpoint Seed Orchard in 1981. This insect has destroyed up to 75 pct. of the cone crop in this seed orchard. A single 0.03 pct. application of permethrin significantly reduced losses of the cone crop when compared to the untreated check (from 75.8 pct. loss to 52.0 pct. loss). Two applications of 0.12 pct. permethrin nearly eliminated cone losses. However, 0.06 pct. permethrin applied once was the most cost effective (Shea and others 1984). The fir coneworm D. abietivorella was the only insect species to cause noticeable damage in the Moscow Seed Orchard in 1984. This insect damaged almost half the cone crop on unprotected trees and reduced seed yield by about 44 pct. Two applications of 0.025 pct. fenvalerate, once in May and once in June, significantly increased seed yield. A single application in mid-June might have been sufficient to prevent coneworm damage, but was not tested. A third application in July was apparently unnecessary.

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Table 2.--Cones harvested per tree, percentage of coneworm-infested[1] cones, and seed per cone for trees treated once, twice, or three times with 0.025% fenvalerate

Treatments[2]	Cones/tree[3]	Infested Cones[3]	Seed/cone[3]	Filled seed[3]	Empty seed[3]	Damaged seed[3]
		Percent		Percent	Percent	Percent
Once	59.8 (8.8)a	13.6 (9.7)b	43.4 (9.0)ab	82.4a	17.1a	0.5a
Twice	62.1 (8.8)a	4.1 (9.7)b	56.0 (9.0)b	84.9a	14.8a	0.3a
Three times	65.8 (8.8)a	5.1 (9.7)b	50.0 (9.0)b	85.5a	13.8a	0.7a
Check	56.8 (6.5)a	46.6 (6.7)a	31.3 (6.6)a	85.9a	13.5a	0.6a

[1]Infested by Dioryctria abietivorella (Groté).

[2]Twenty-two trees were untreated and 12 trees each received either one, two, or three applications of fenvalerate.

[3]Mean (±95% confidence limit). Means in a column followed by the same letter are not significantly different by Bonferroni's t-statistic at the $\alpha = 0.05$ level (Miller 1980).

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